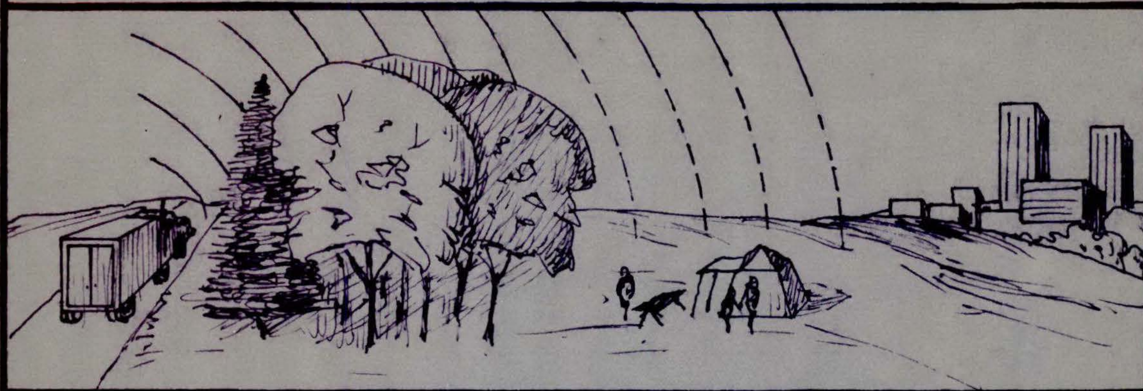
3 of

TREES AND SHRUBS FOR



NOISE ABATEMENT

PRELIMINARY REPORT
OF A STUDY
CONDUCTED BY THE
UNIVERSITY OF NEBRASKA
AND THE
U.S. FOREST SERVICE

SUBMITTED TO:
FOREST SERVICE
U.S. DEPARTMENT OF AGRICUTURE
WASHINGTON, D.C.

DAVID I. COOK: DEPT. OF ENGINEERING MECHANICS, UNIVERSITY OF NEBR.
DAVID F. VAN HAVERBEKE: ROCKY MT. FOREST AND RANGE EXPERIMENT STA.

TREES AND SHRUBS

FOR NOISE ABATEMENT

A Preliminary Report of a Study Conducted by

The University of Nebraska and the U.S. Forest Service

Principal Investigator: David I. Cook - Department of Engineering Mechanics

Research Forester: David F. Van Haverbeke - Rocky Mountain Forest and Range Experiment Station

February 1970

TABLE OF CONTENTS

FOREWORD

The study, "Trees and Shrubs for Noise Abatement", was conducted as a joint effort by the University of Nebraska and the U. S. Forest Service. The Department of Engineering Mechanics and the Rocky Mountain Forest and Range Experiment Station provided the necessary personnel.

The principal objective was to determine the effectiveness of trees and shrubs in reducing sound levels, wherever intrusive noise is a problem.

Personnel serving in the project were Professor David I. Cook, Department of Engineering Mechanics, principal investigator; Dr. David F. Van Haverbeke, Research Forester, Rocky Mountain Forest and Range Experiment Station, USDA, and Mr. Thomas Young, student of Architecture and Community planning, University of Nebraska. Credit is due Mr. G. Lloyd Hayes, Assistant Director of the Rocky Mountain Forest and Range Experiment Station (retired), for efforts in getting the project underway, to Dr. John C. Barber, Chief, Branch of Forest Genetics, Division of Timber Management Research, U. S. Forest Service, for negotiating the supporting grant by the Forest Service to the University of Nebraska, and to Dean John R. Davis for assisting in the final negotiations and in the preparation of the original budget request.

INTRODUCTION

Excessive noise is a form of environmental pollution which has received increasing popular attention in recent years. Trees and other forms of vegetation are known to have some effect on the transmission of sound, but precise information is lacking.

The use of trees and shrubs as traffic noise screens has been proposed, but, because of this lack of knowledge, the opinions expressed on their value appear to be largely a matter of conjecture.

The present study is an attempt to provide accurate information on the use of trees and shrubs for the above purpose, and to add to the body of knowledge in the area of sound transmission. Actual tree plantings in the form of 25 to 30 year old shelterbelts and windbreaks on the plains of Nebraska were used in the study.

Traffic noises produced by trucks, passenger cars and city busses were recorded on magnetic tape to provide the sound source. The pre-recorded sound was played back through the tree barriers, and the sound level was measured behind the barriers at varying distances.

The subjective measurement of noise is such a complicated process that no direct reading instrument is available for evaluating the apparent loudness of all types of sounds. However the dBA scale has received considerable acceptance in rating broad-band noises, such as traffic noises. The scale is logarithmic in character, and each 10 decibel difference (for the usual range of sounds) represents approximately a two-fold change in apparent loudness. This is a sizeable difference, and would correspond to a reduction from the 60 dBA level of a typical noisy accounting office to the 50 dBA level of a private business office.

Because of the ease of application and its general acceptance, the dBA scale was used for many of the measurements, and for all results reported in this preliminary study. Field measurements consisted of sound level (dBA) and sound pressure level (dB flat response); the sound was also recorded on magnetic tape for later analysis. The foregoing procedures were repeated at nearby locations under similar conditions, but without the trees, for the purpose of comparison, and to evaluate, thereby, the use of trees in the reduction of traffic noise.

Results of the study are in the form of experimental curves and their equations, derived from the data by digital computer application. Curves and equations included in the report are limited to several typical test runs, but curves based on the average of a number of test runs for a specific belt of trees are also shown. Ordinates of the curves are sound level (dBA) versus microphone distance. One type of curve is so constructed that expected sound levels, with trees present, may be read directly. Decrease of sound level (technically termed "attenuation") may also be read directly. The sound level without trees, although not readable directly, may be obtained, if desired, by applying the attenuation to the original "tree-curves".

The Preliminary Report is made available approximately 10 months before the anticipated completion date of the final report. This has been done in the interest of time, with some sacrifice in the area of wind effect on sound transmission, and alternate methods for reporting apparent loudness.

The results reported, while incomplete, are believed to be within the range of accuracy required for most practical applications. Final results are expected to be in the nature of refinements, extension to hard-surface comparisons, and to alternative forms of loudness evaluation.

Conclusions for the report are in two forms:

1. Numerical sound level reductions in decibels (dBA) which may be expected for specific planting configurations, and,

2. General conclusions pertaining to the relative importance of trees and shrubs in the overall picture of noise reduction. Recommendations for the use of trees and shrubs as noise screens include desirable types of trees, and placement and depth of tree belts for expected sound levels under specific conditions.

SUMMARY

The potential value of trees as noise screens, as determined from the present study of a variety of shelter belts in southeastern Nebraska, appears to be very good. Reductions in noise levels in the order of 10 decibels (approximately half as loud) are not uncommon, and the likelyhood of even greater reduction is probable, where the tree structure could be designed specifically for noise protection.

A limited study of noise reductions of tree belt and grass combinations relative to hard surfaces, gave exceptionally large sound reductions, in the order of 15 dBA, (approximately a 3-fold reduction in apparent loudness). This appears to be a fertile area for continued study, and emphasizes the need for interrupting wide expanses of concrete with the softer surfaces provided by trees, shrubs and grass.

The relative effects of tree species, height and belt width has not been firmly established at this writing, but it appears that species do not differ greatly in their ability to reduce noise levels. Thus it would seem desirable to use evergreen varieties, where year-round noise screening is desired.

Distances of at least 75 feet from sound source to protected area are necessary for optimum noise screening, although the use of shorter shrubs and grass will give some protection for lesser distances.

CHAPTER I

EQUIPMENT AND FACILITIES

Selection of Test Sites

Tree belts of varying widths, heights and types were selected for the research experiments. Many of the belts had been planted during the "Dust-Bowl" days of the late 1930's and early 1940's, under the U. S. Forest Service directed Prairie States Forestry Project. These plantings were established to provide man, beast, and crops protection from the strong winds so prevalent on the Plains, and to reduce the loss of top soil from wind erosion. Flat terrain was a requirement for the study of noise abatement, to eliminate the influence of hills and valleys on the noise transmission. Relatively quiet locations, removed from major highways were chosen to eliminate interference due to traffic and other extraneous noises.

Most of the sites selected were within 100 miles northwest of Lincoln, Nebraska. Photographs and descriptions of the sites appear in Chapter III, where results of the tests are reported.

Development of the Noise Source

Three major types of noise were selected for final study, from among the different noises initially considered: Type 1, highway truck noise; Type 2, arterial auto noise; and Type 3, bus stop noise. Aircraft, train and motorcycle noises were not used because of the greater feasability of other methods of noise reduction in these cases.

Selected noises were tape recorded, and the noises were analyzed in octave band widths. The analyzed noises were then compared with each other and with similar noises, which had been analyzed by other experimenters.

The purpose of the comparison was to learn if the noises selected were truly representative of the particular types studied. They were found to be substantially so. Octave band spectra of the three noises appear in graphical form in Fig. 1.

TRAFFIC NOISE ANALYSIS

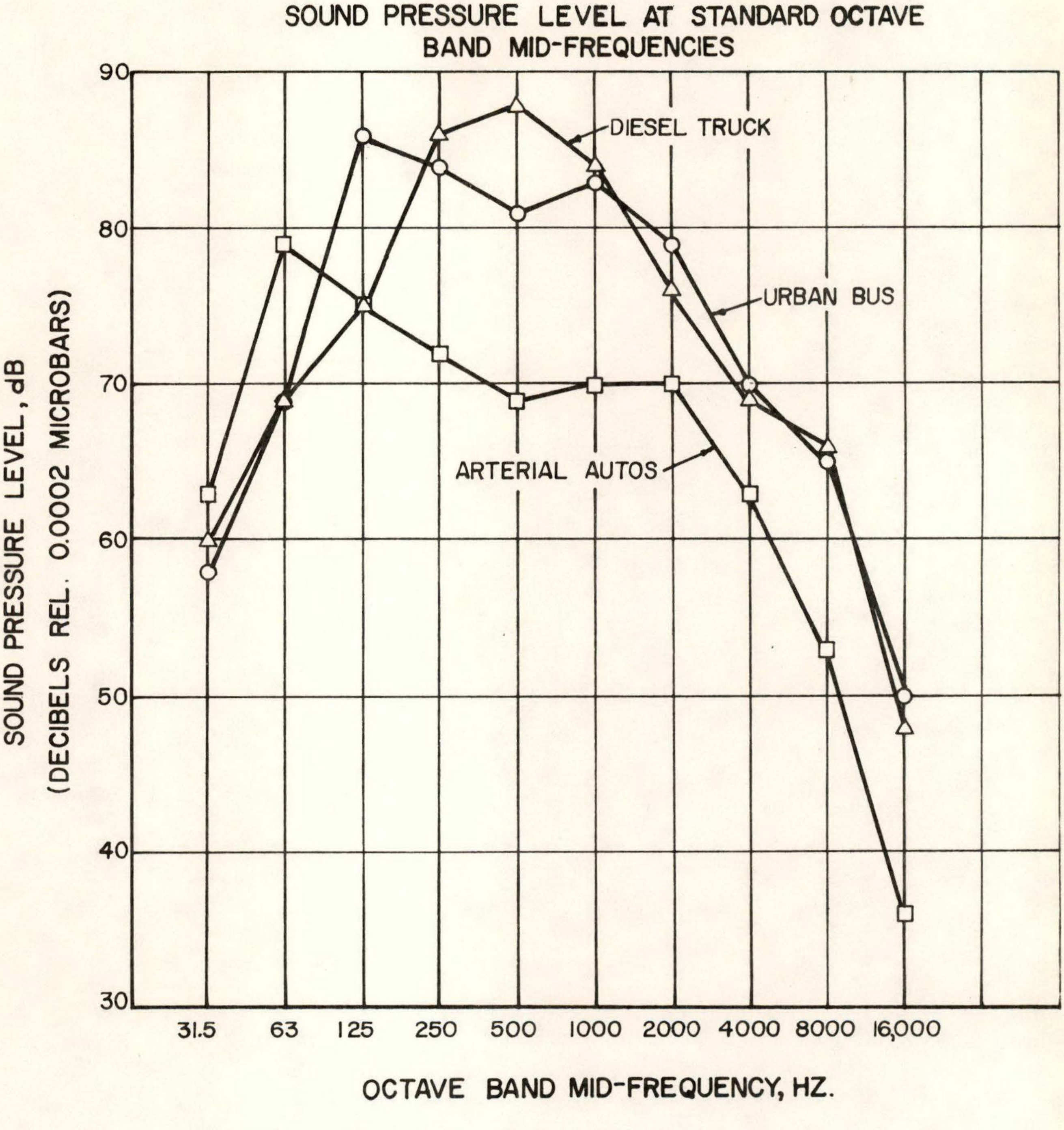


Fig. 1.

Noise type 1, from a deisel semi-trailer, was recorded at an Interstate 80 Rest Area about 18 miles west of Lincoln, Nebraska.

Noise type 2, from a stream of 40 mph arterial traffic was recorded on a main street in Lincoln, Nebraska during the 5:00 p.m. rush hour.

Noise type 3, from a City Lines GMC Bus, was recorded at a downtown bus stop location in Lincoln, Nebraska.

The original tape recordings were formed into "tape loops", and these loops were re-recorded on a master tape. Sound on the master tape consisted of a series of 10 second "noise bursts" of the three types of noise. Each burst in the series was repeated 10 times, and the entire series was repeated 5 times, making a total of 150 noise bursts on the master tape.

One replay of the master tape corresponded to one test run at a particular site.

Description of Equipment

Major items of equipment consisted of a portable electric generator, a tape recorder, a high output sound system, a magnetic tape data recorder and sound level meter, a ceramic microphone, and a microphone calibrator. Meterological equipment included thermometers, hygrometer, and wind speed and direction indicator. Supplementary equipment included a portable tape recorder, a portable sound level meter, and necessary mounting devices and connecting cables. An Electro-voice "Acoustifoam" windscreen was used to cover the microphone, and a secondary cloth-covered wire wind screen was also used to eliminate wind blast at wind velocities over 15 miles per hour. A detailed listing of the equipment follows:

120 v A.C. 1600 Watt Alternator - Sears Roebuck Model 580.5508.1

Tape Recorder and Playback unit Ampex model 602

Audioamplifier 175 watt; Altec No. 1520-B

Driver Loudspeaker 100 watt, Altec No. 290-D

Multicellular Horn - Altec No. 203-B

Bass Reflex Sound Cabinet - Altec No. 825 w/515 speaker

Cross-over network - Altec No. N500-C

Data Recorder - General Radio No. 1525A

Microphone - General Radio Type 1560-P5

Octave Band Analyzer Type 1558BP

Sound Level Calibrator, General Radio Type 1562-A

Windscreen, Electro-Voice Type 524-A

CHAPTER II

RESEARCH APPROACH AND PROCEDURE

Experimental Procedure

The three noise types previously recorded were projected by the high-output sound system at levels comparable to their recorded sound levels. Output levels were checked by a portable sound level meter, which was calibrated daily, using a General Radio sound level calibrator Type 1562-A. The sound was projected through tree belts of various types, having different heights, depths and densities. The sound level was then measured at varying distances of 25, 50, 100, 200, and 300 feet behind the trees. Measurements of sound level (dBA) and sound pressure level (dB flat response) were recorded. The average of five readings was computed for each position of the microphone. The attenuated sounds were also tape recorded for later analysis. For certain adaptable test sites, the noise source was placed at distances of 25, 50, and 100 feet in front of the trees, in an effort to determine the optimum placement of trees between the noise source and the protected location.

Control test runs (similar to regular test runs but without trees) were designed to duplicate as nearly as possible the physical conditions of the regular test runs, so that the effect of the trees alone could be observed. Control runs were made immediately following regular test runs, to minimize the effect of variations of temperature gradients, humidity and wind velocity. Also nearby locations, with similar terrain were used, where possible, to minimize the effect of varying topography and surface conditions. Where a similar surface could not be used, a correction in sound level was applied to account for the different effects of the regular test run surface and the control test run surface. Special tests were run to obtain "surface correction factors" for these cases.

Initial results of the experiments are in the form of tabulated sound pressue level readings (dB) and sound level readings (dBA). The sound was also tape recorded at the various microphone positions, for later analysis and evaluation in the laboratory.

Reduction of Experimental Data

Curves were plotted by computer to show graphically the relationship of sound level (dBA) versus distance behind trees. The method of least squares was used to obtain a "best fit". Difference curves of sound levels with and without trees were also drawn by computer. These "attenuation" or difference curves were averages of a number of readings for each belt of trees studied. The immediate purpose of the attenuation curves was to show the probable overall effect of different tree belt configurations on the reduction of noise.

Data were reduced to preliminary graphs which were individually corrected by the process of fairing, to account for minor experimental variations and for control run surface variations. New points were read from the corrected graphs, and final curves were drawn to show average sound levels behind the trees at varying distances from the noise source. Attenuation curves were also drawn on the same graph. These curves show the corresponding sound reduction caused by trees. Graphs containing the curves appear in Chapter III of the report.

CHAPTER III

RESULTS OF EXPERIMENTS

Form of Results

Each belt of trees is pictured in a photograph, which is followed by a descriptive schematic drawing. Graphs of the noise reduction characteristics of a belt follow the schematic drawing.

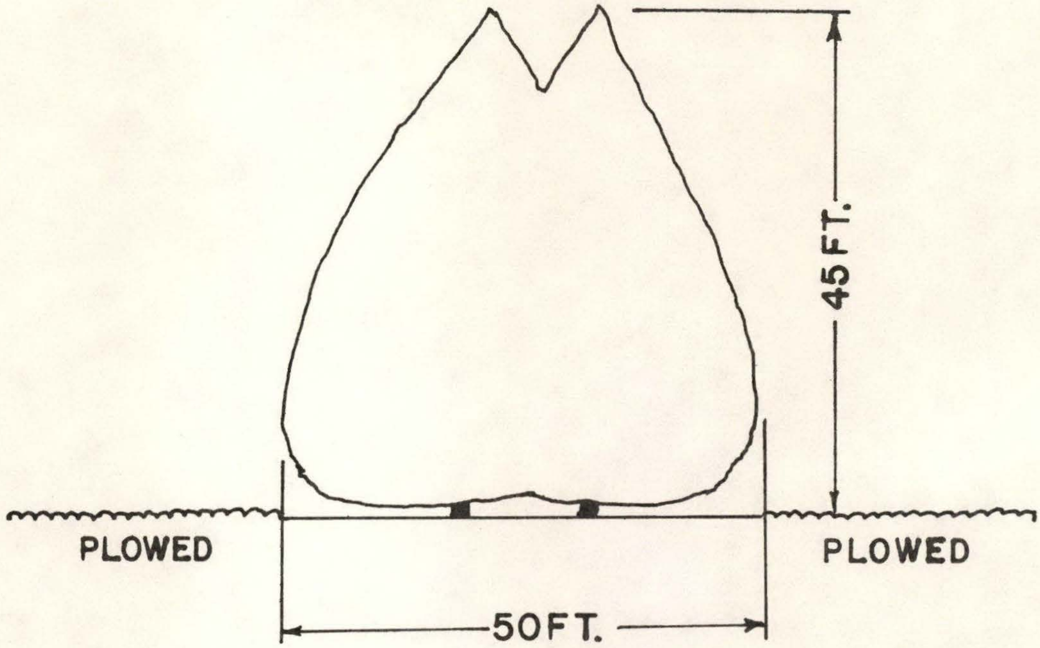
The graphs are of three types. The first type plotted by computer from the original data shows the average sound level in dBA units at distances of 25, 50, 100, 200 and 300 ft behind the belt of trees. The curves of the graph are fitted to the data by the method of least squares. Data and curves for the control run (no trees) are also shown on the graph. The legend used refers to noise type and test run number, for example, sound number 1-1 is noise type 1, test run no. 1 (a regular run) whereas 1-2 is noise type 1 test run 2 (a control run). An odd number following the dash represents a regular test run, whereas an even number following the dash represents the corresponding control run. Noise types 1, 2 and 3 are from a diesel truck, a stream of arterial autos, and an urban bus respectively. This first type of graph has not been corrected for noise source distance and belt width, and is therefore unsuitable for direct application.

The second type of graph is drawn by hand. It shows the sound level in dBA units at distances up to about 450 feet from the noise source. The three types of noise are represented by a group of separate curves. Sound levels at various distances from the noise source (with trees present) may be read directly from this group. A second set of 3 curves is drawn below the noise level curves to show the corresponding reduction in noise caused by the trees. These curves are called "excess attenuation" curves,

and are so termed because they show the sound reduction (attenuation) due to the trees alone. This is in excess of the natural attenuation due to distance, atmosphere, ground absorption, and other effects.

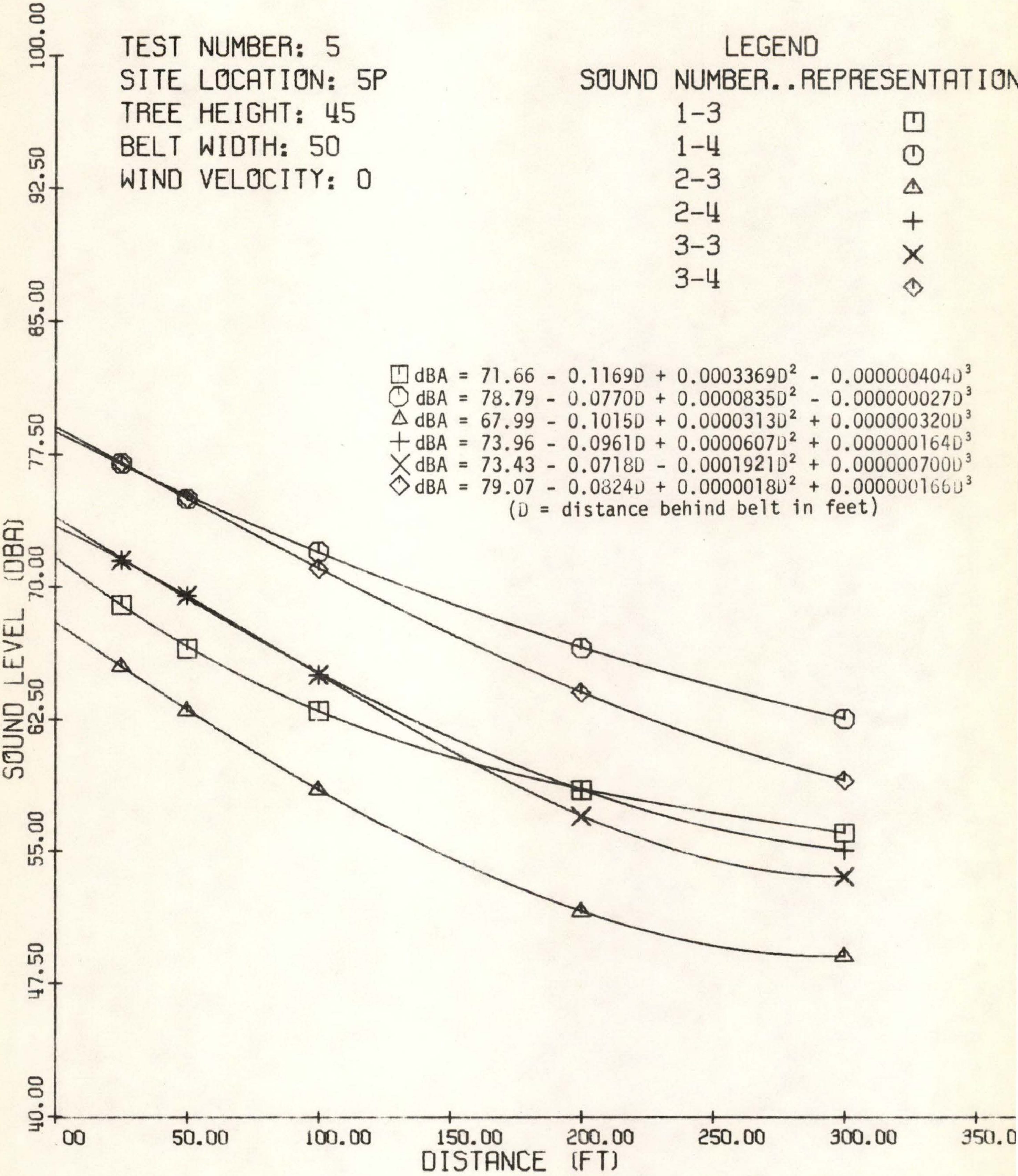
The third type of graph, plotted by computer, shows the average attenuation of several test runs on the same belt of trees. It should provide a more accurate measure of the noise reduction characteristics of a particular belt than would a curve derived from the results of a single test.

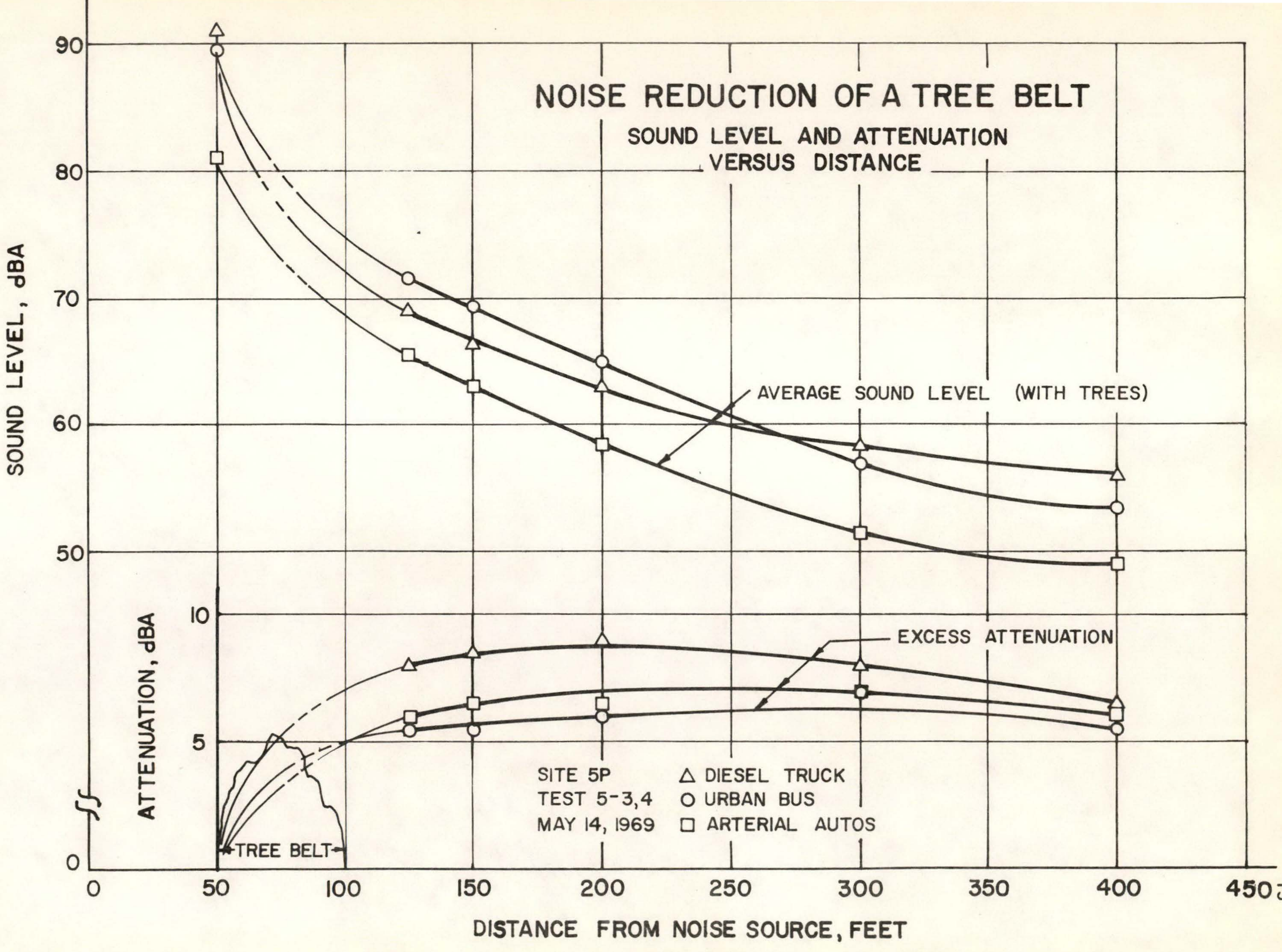
A graph entitled, "Sound Levels and Attenuation", appearing on page 42, is different from the others, and deserves special mention. It is intended to show the relative effects of trees, soft ground surfaces, and hard surfaces on the reduction of noise, and in addition, the range of sound reduction (attenuation) which may be expected for a wide variety of surface conditions. This curve will be referred to again in Chapter IV "Conclusions".

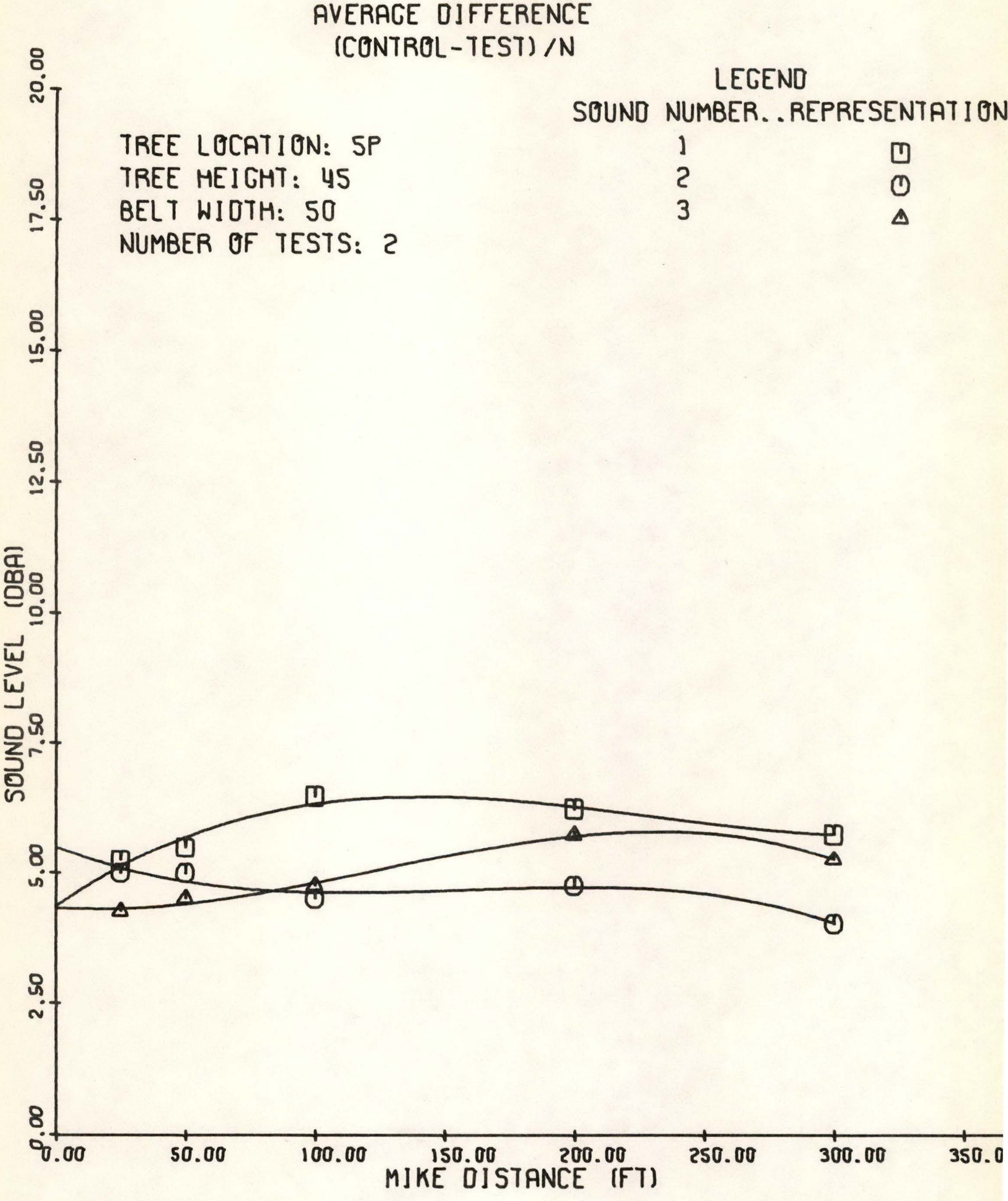


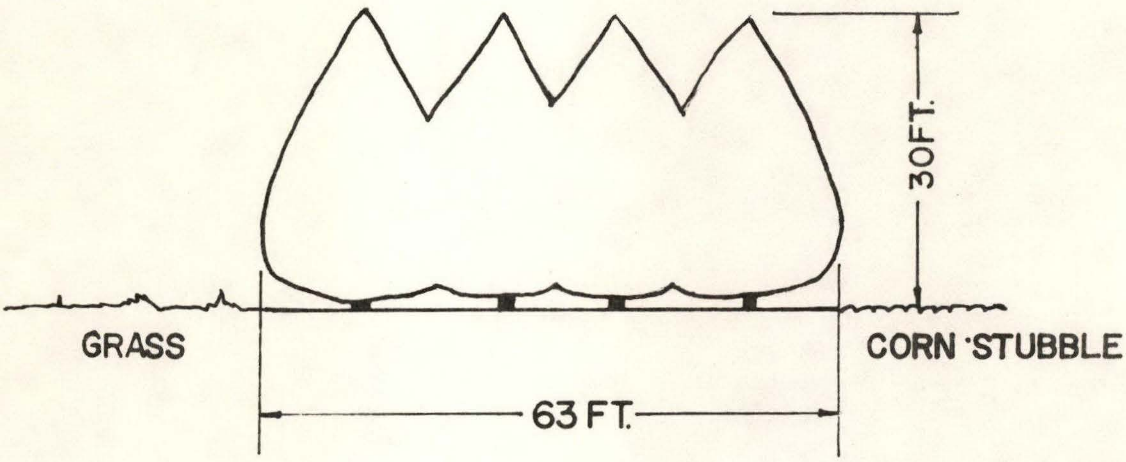
BELT NO. 5P AUGUSTIN BROS. FARM

2 ROWS EASTERN RED CEDAR 45 FEET TALL
BETWEEN-ROW SPACING 8 FT.
IN-ROW SPACING 8 FT.
BELT WIDTH 50 FT.


TEST NUMBER: 5
SITE LOCATION: 5P
TREE HEIGHT: 45
BELT WIDTH: 50
WIND VELOCITY: 0
LEGEND
SOUND NUMBER..REPRESENTATION
1-3
1-4
2-3
2-4
3-3
3-4
dBA = 71.66 - 0.1169D + 0.0003369D² - 0.000000404D³
dBA = 78.79 - 0.0770D + 0.0000835D² - 0.000000027D³
dBA = 67.99 - 0.1015D + 0.0000313D² + 0.000000320D³
dBA = 73.96 - 0.0961D + 0.0000607D² + 0.000000164D³
dBA = 73.43 - 0.0718D - 0.0001921D² + 0.000000700D³
dBA = 79.07 - 0.0824D + 0.0000018D² + 0.000000166D³
(D = distance behind belt in feet)
SOUND LEVEL (DBA)
100.00
92.50
85.00
77.50
70.00
62.50
55.00
47.50
40.00
00
50.00
100.00
150.00
200.00
250.00
300.00
350.0
DISTANCE (FT)

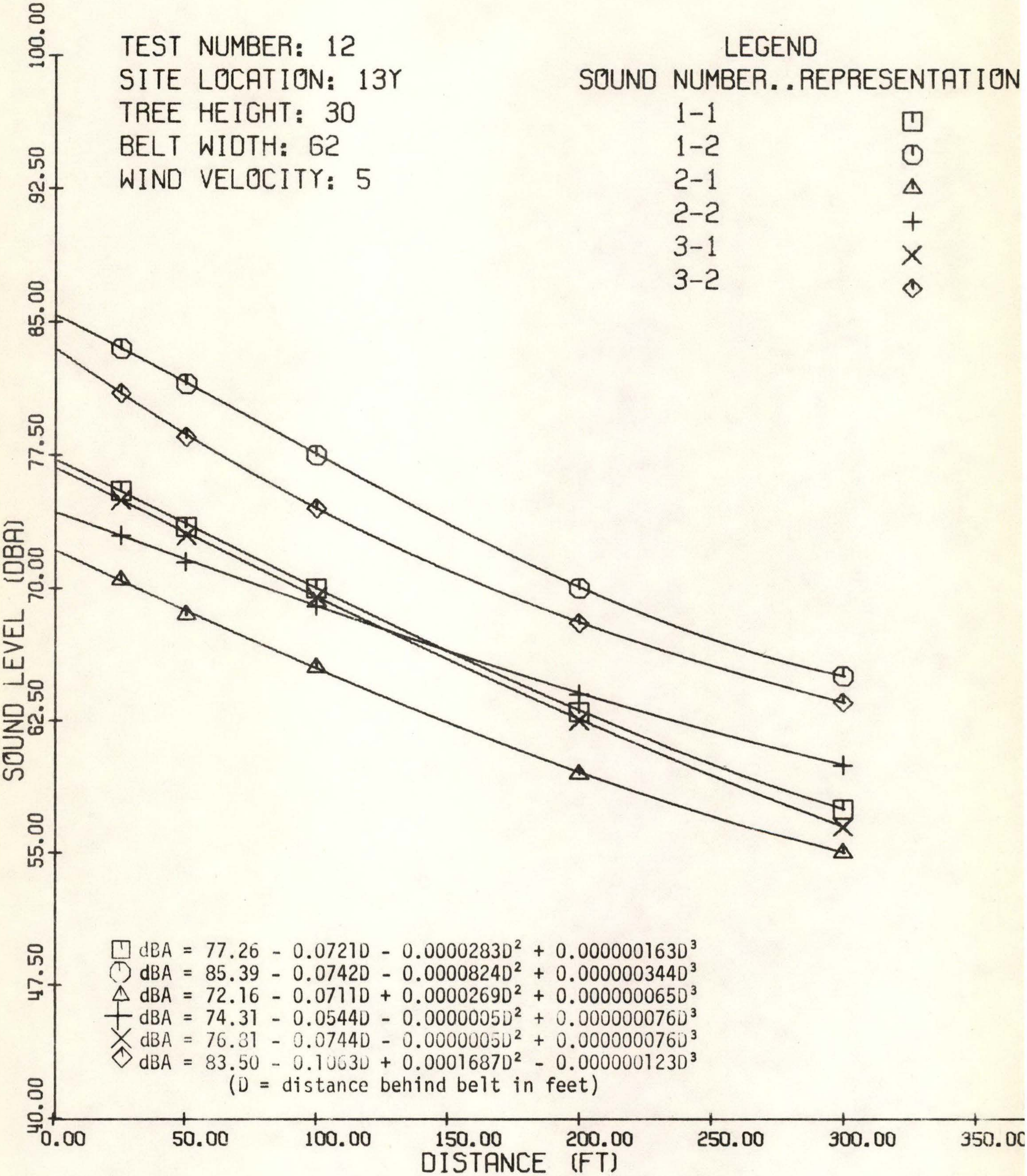

NOISE REDUCTION OF A TREE BELT
SOUND LEVEL AND ATTENUATION VERSUS DISTANCE
AVERAGE SOUND LEVEL (WITH TREES)
EXCESS ATTENUATION
SITE 5P
TEST 5-3,4
MAY 14, 1969
△ DIESEL TRUCK
○ URBAN BUS
□ ARTERIAL AUTOS
TREE BELT
SOUND LEVEL, dBA
ATTENUATION, dBA
DISTANCE FROM NOISE SOURCE, FEET
90
80
70
60
50
10
5
0
0
50
100
150
200
250
300
350
400
450

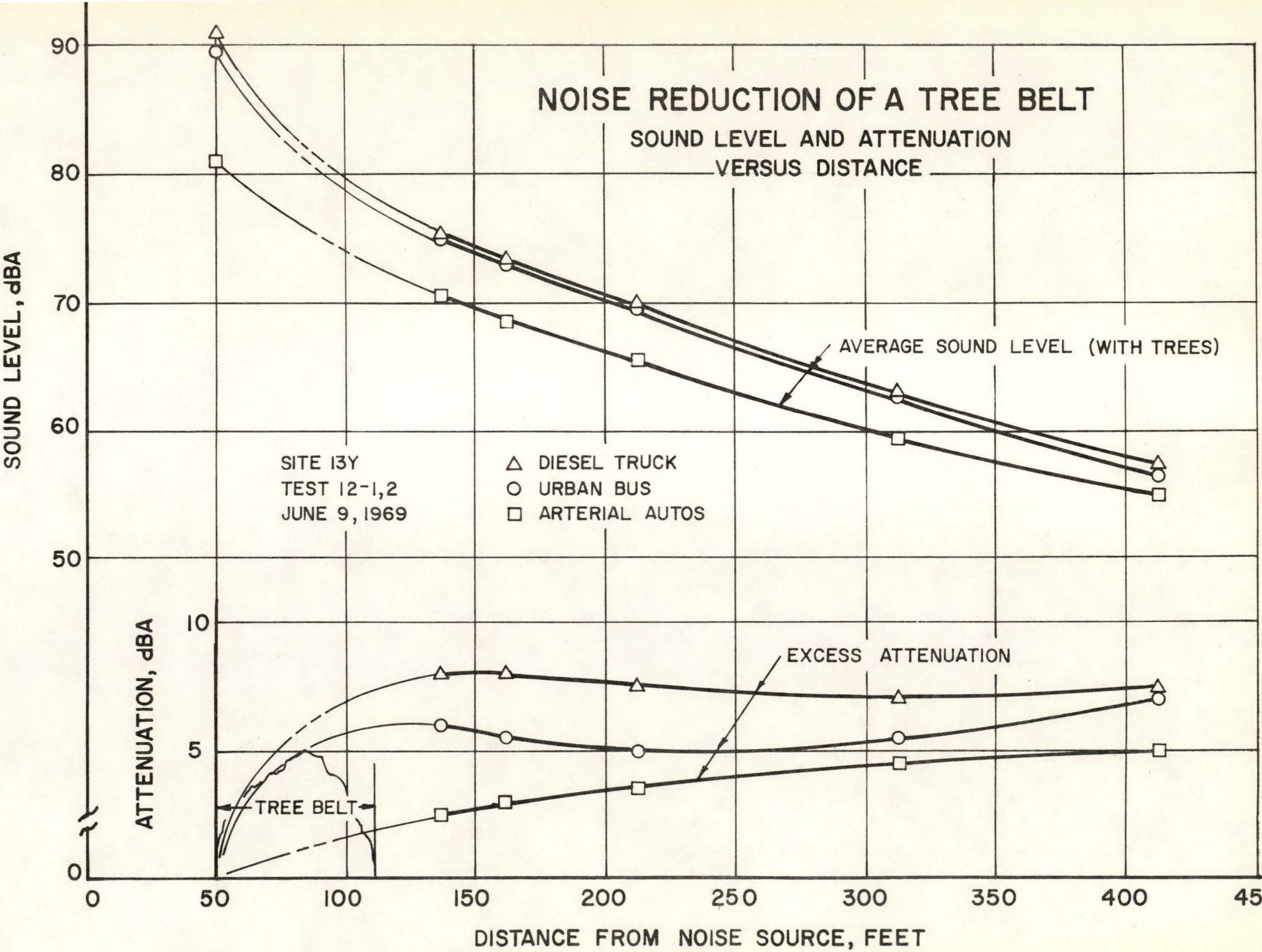

AVERAGE DIFFERENCE
(CONTROL-TEST)/N
LEGEND
SOUND NUMBER..REPRESENTATION
1
2
3
TREE LOCATION: SP
TREE HEIGHT: 45
BELT WIDTH: 50
NUMBER OF TESTS: 2
SOUND LEVEL (DBA)
0.00
2.50
5.00
7.50
10.00
12.50
15.00
17.50
20.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.0
MIKE DISTANCE (FT)

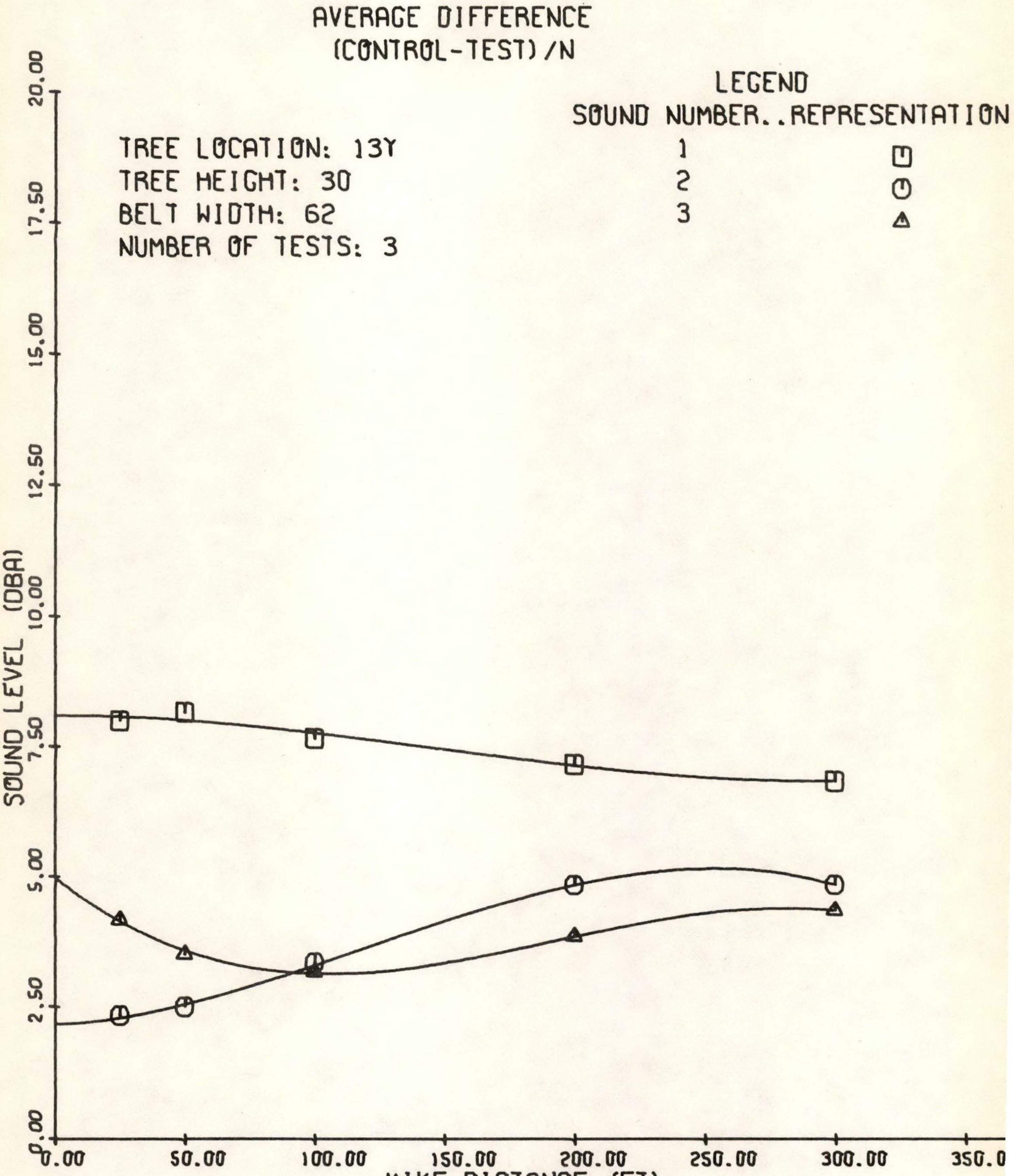


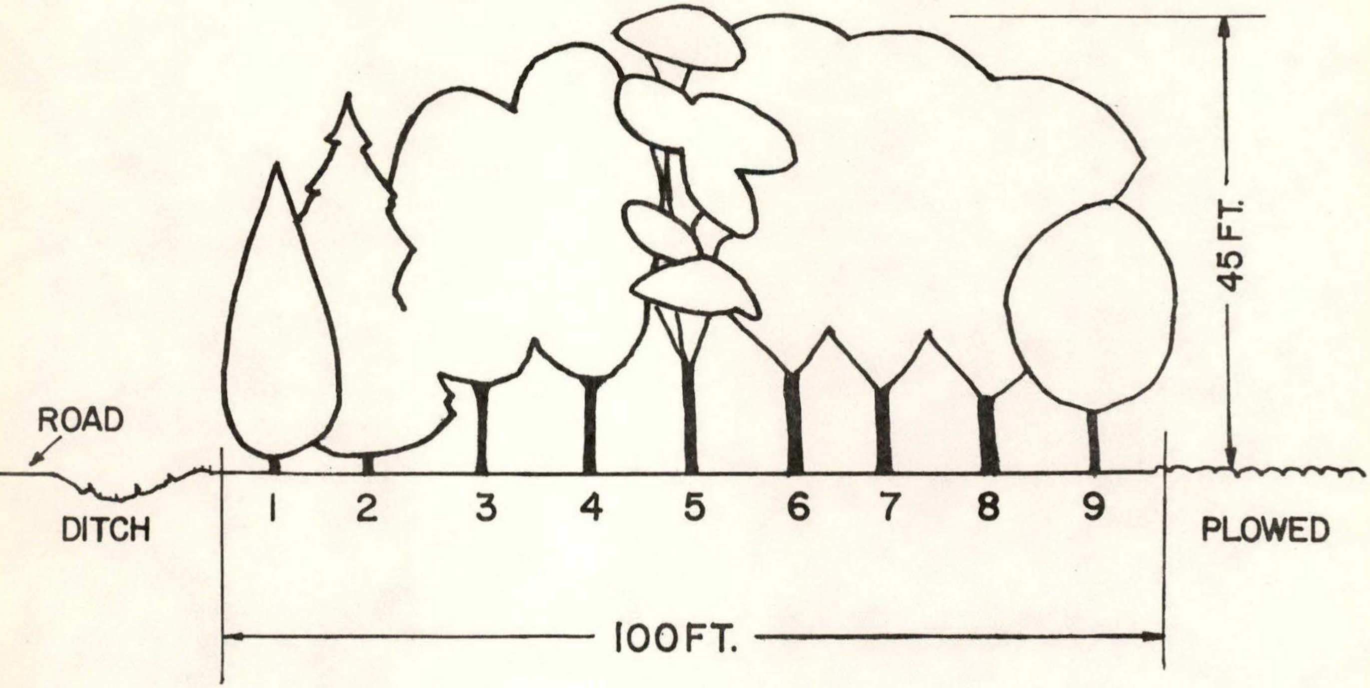
BELT NO. 13Y LLOYD McLAIN FARM

4 ROWS EASTERN RED CEDAR 30 FEET TALL
BETWEEN-ROW SPACING 12 FT.
IN-ROW SPACING 9 FT.
BELT WIDTH 63 FT.


TEST NUMBER: 12
SITE LOCATION: 13Y
TREE HEIGHT: 30
BELT WIDTH: 62
WIND VELOCITY: 5
LEGEND
SOUND NUMBER..REPRESENTATION
1-1
1-2
2-1
2-2
3-1
3-2
SOUND LEVEL (DBA)
100.00
92.50
85.00
77.50
70.00
62.50
55.00
47.50
40.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
DISTANCE (FT)
dBA = 77.26 - 0.0721D - 0.0000283D² + 0.000000163D³
dBA = 85.39 - 0.0742D - 0.0000824D² + 0.000000344D³
dBA = 72.16 - 0.0711D + 0.0000269D² + 0.000000065D³
dBA = 74.31 - 0.0544D - 0.0000005D² + 0.000000076D³
dBA = 76.81 - 0.0744D - 0.0000005D² + 0.000000076D³
dBA = 83.50 - 0.1063D + 0.0001687D² - 0.000000123D³
(D = distance behind belt in feet)


NOISE REDUCTION OF A TREE BELT
SOUND LEVEL AND ATTENUATION
VERSUS DISTANCE
SOUND LEVEL, dBA
90
80
70
60
50
AVERAGE SOUND LEVEL (WITH TREES)
SITE 13Y
TEST 12-1,2
JUNE 9, 1969
△ DIESEL TRUCK
○ URBAN BUS
□ ARTERIAL AUTOS
ATTENUATION, dBA
10
5
0
EXCESS ATTENUATION
TREE BELT
0
50
100
150
200
250
300
350
400
450
DISTANCE FROM NOISE SOURCE, FEET


AVERAGE DIFFERENCE
(CONTROL-TEST)/N
LEGEND
SOUND NUMBER..REPRESENTATION
1
2
3
TREE LOCATION: 13Y
TREE HEIGHT: 30
BELT WIDTH: 62
NUMBER OF TESTS: 3
SOUND LEVEL (DBA)
0.00
2.50
5.00
7.50
10.00
12.50
15.00
17.50
20.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.0
MIKE DISTANCE (FT)

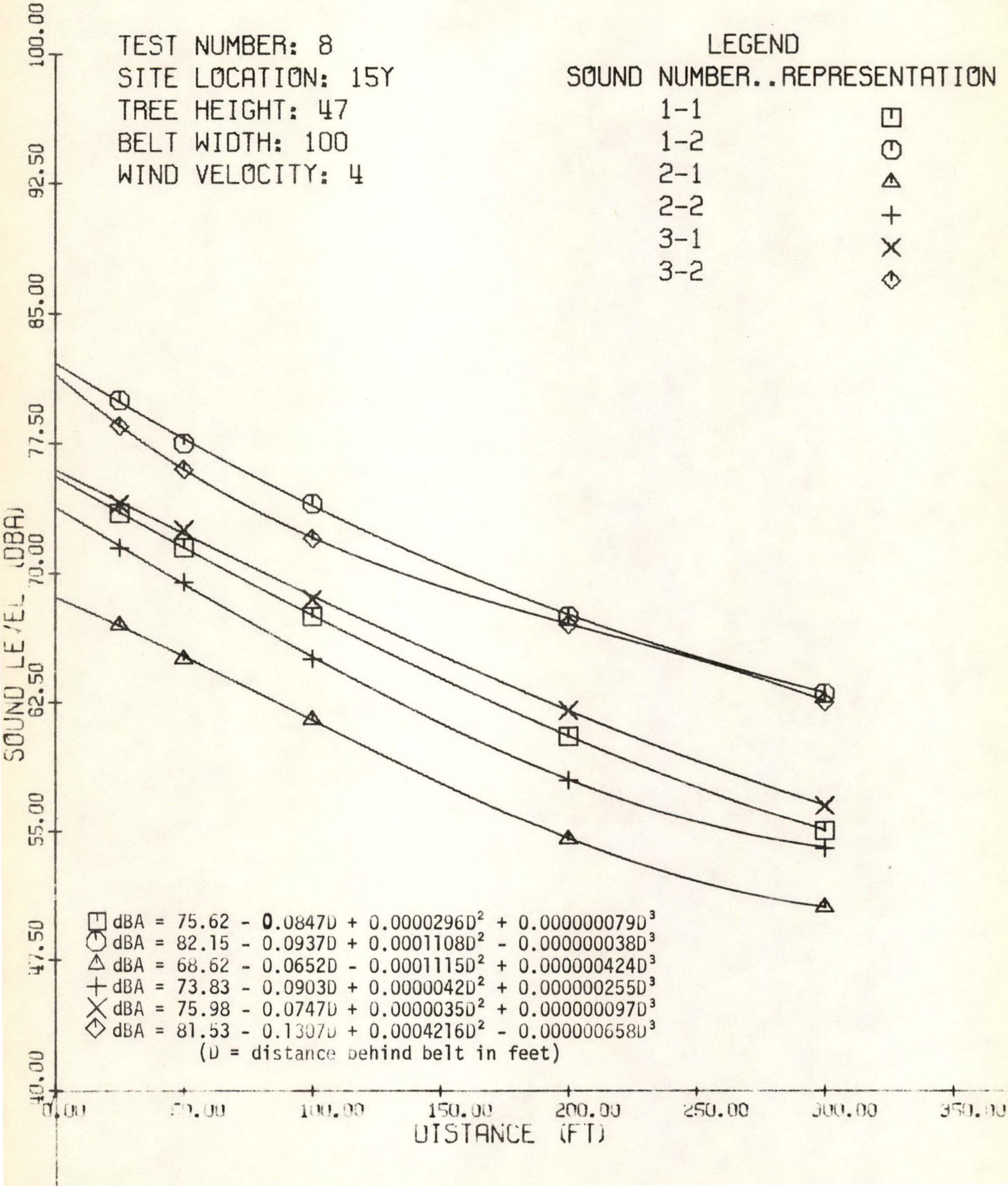


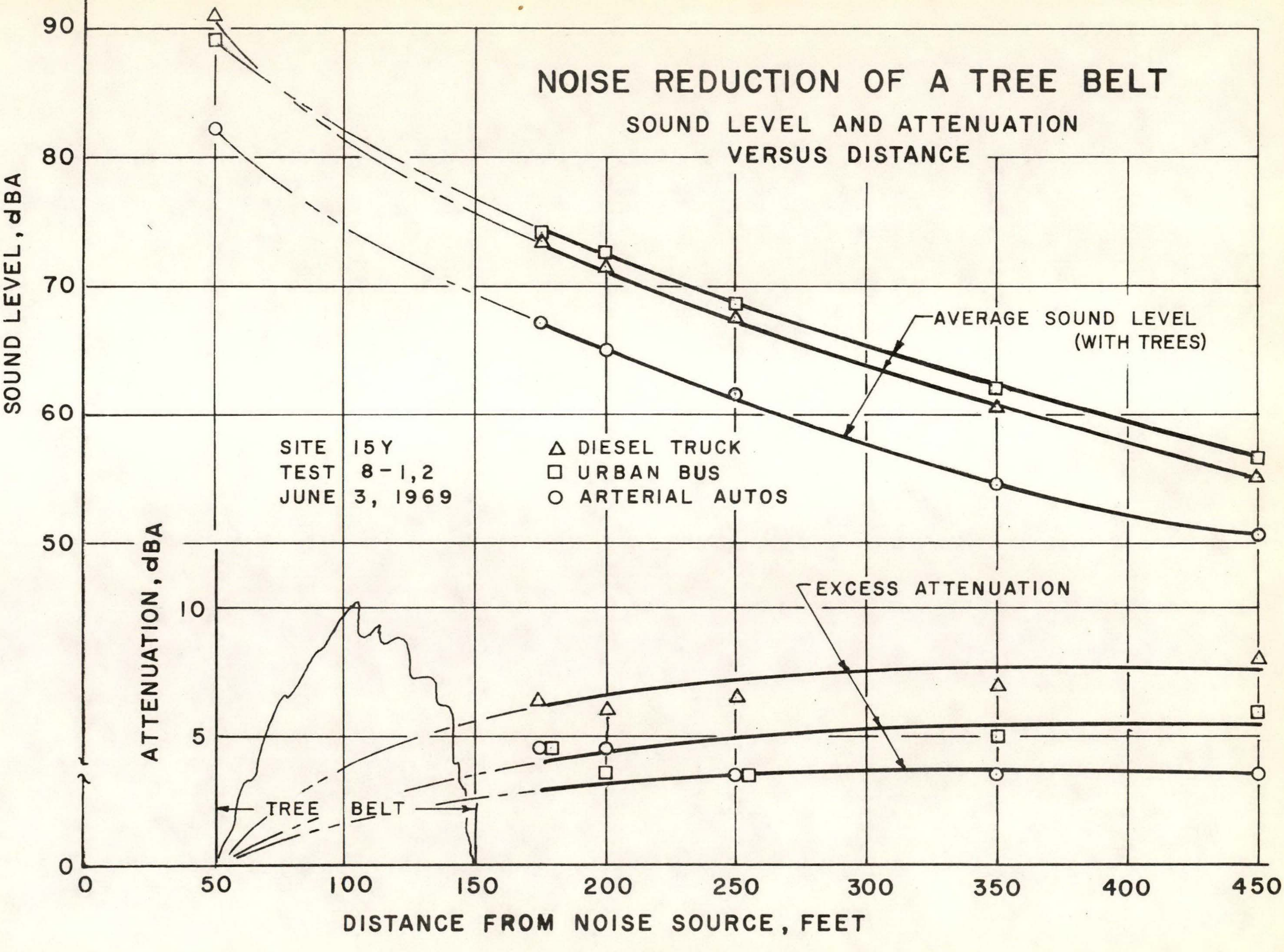
BELT NO. 15Y IRVIN & HELEN RAFERT FARM

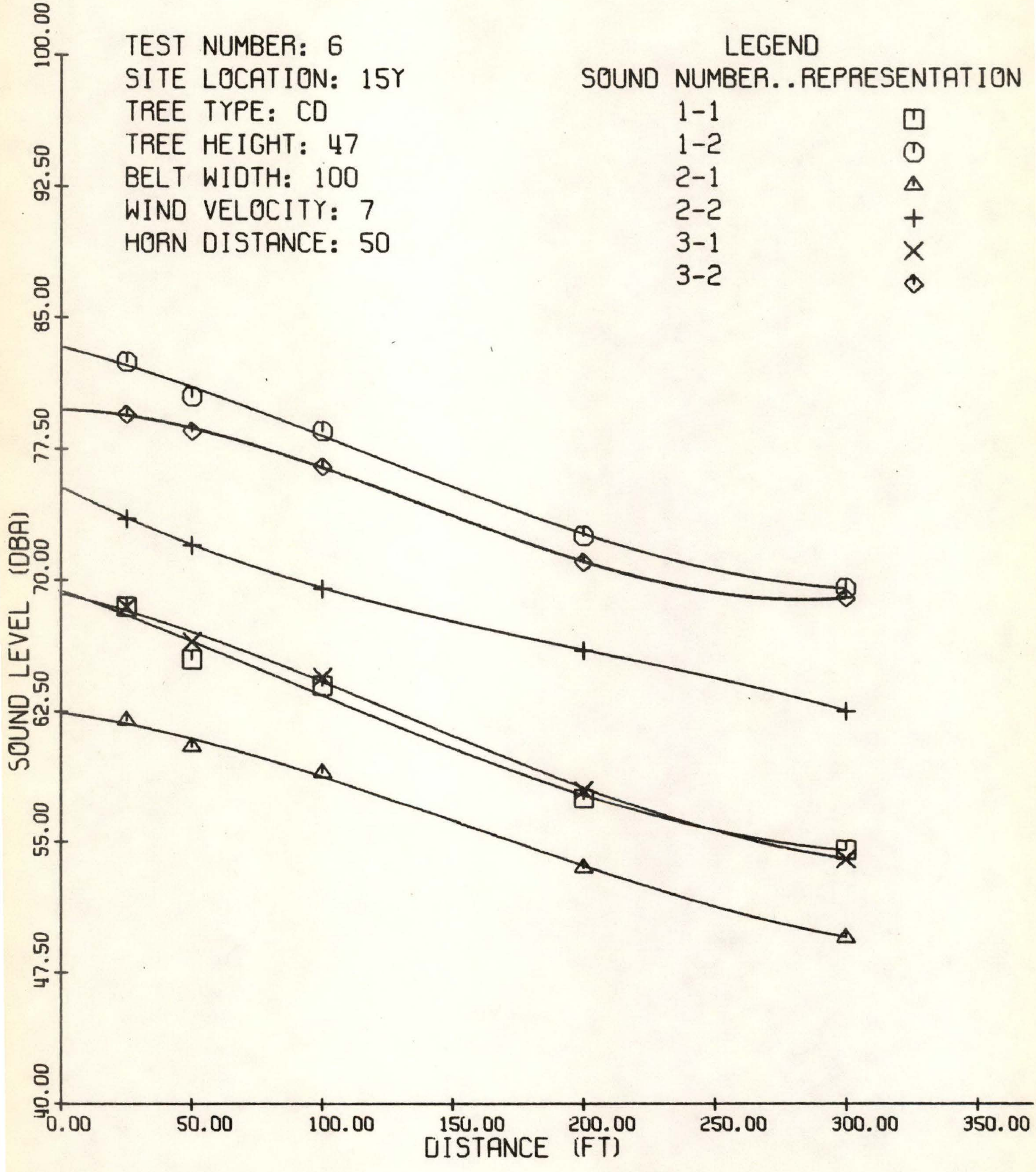
9 ROW BELT S. TO N. 45 FEET TALL

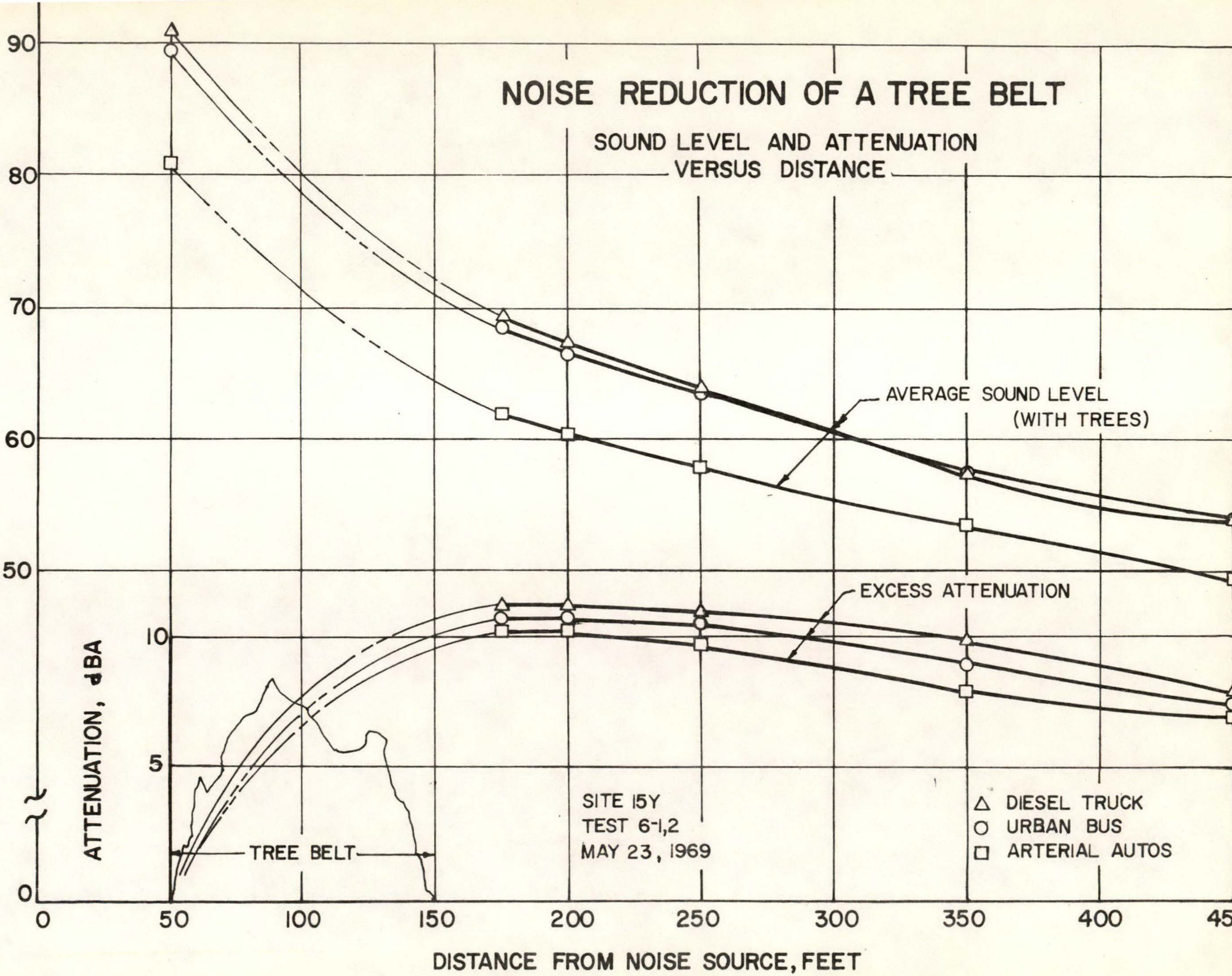
1. EASTERN RED CEDAR
2. PONDEROSA PINE
3. GREEN ASH
4. HACKBERRY
5. HONEY LOCUST
6. SIBERIAN ELM
7. SIBERIAN ELM
8. AMERICAN ELM
9. MULBERRY

BETWEEN-ROW SPACING 10 FT.
IN-ROW SPACING 6 FT.
BELT WIDTH 100 FT

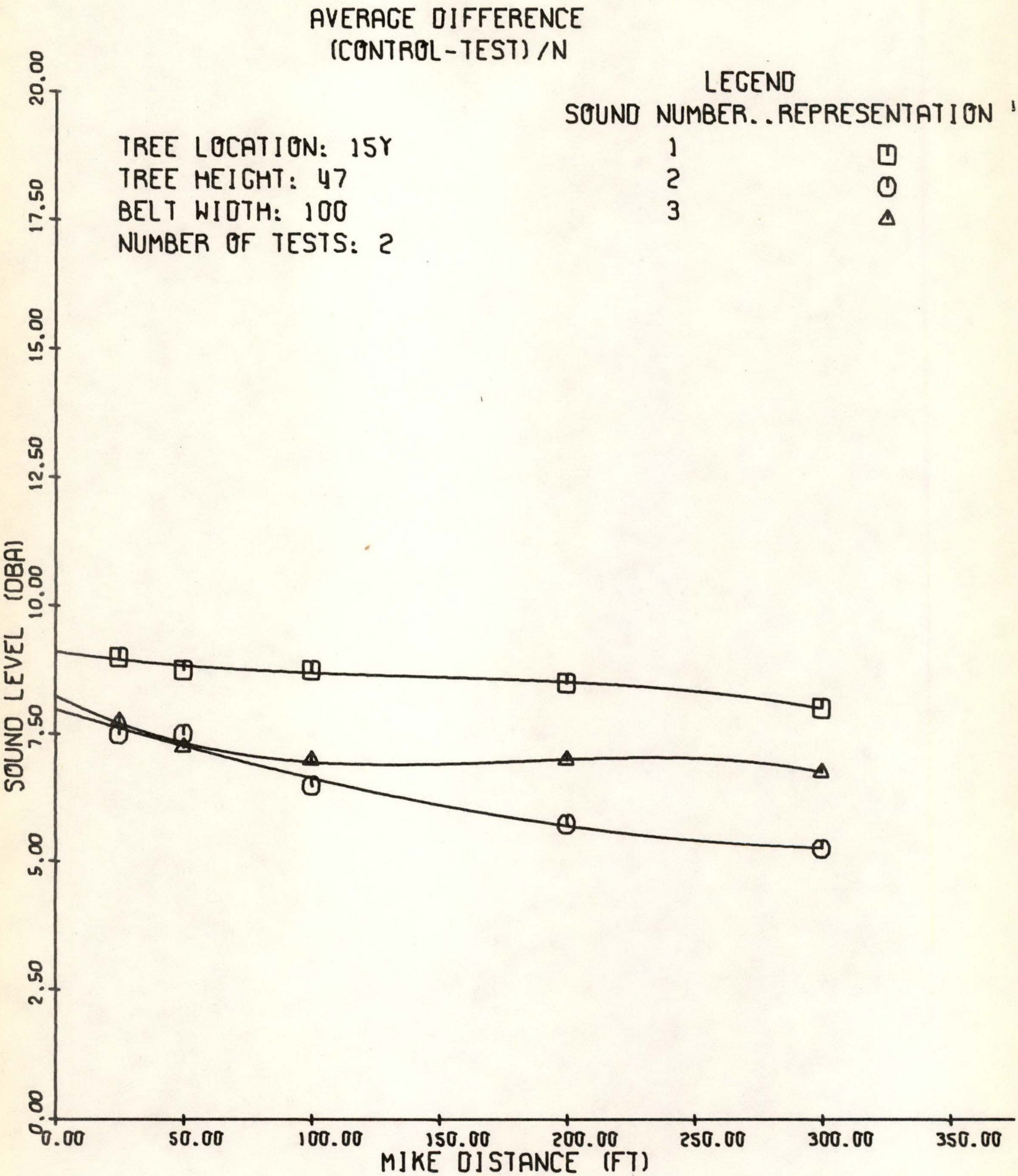

TEST NUMBER: 8
SITE LOCATION: 15Y
TREE HEIGHT: 47
BELT WIDTH: 100
WIND VELOCITY: 4
LEGEND
SOUND NUMBER..REPRESENTATION
1-1
1-2
2-1
2-2
3-1
3-2
$dBA = 75.62 - 0.0847D + 0.0000296D^2 + 0.000000079D^3$
$dBA = 82.15 - 0.0937D + 0.0001108D^2 - 0.000000038D^3$
$dBA = 68.62 - 0.0652D - 0.0001115D^2 + 0.000000424D^3$
$dBA = 73.83 - 0.0903D + 0.0000042D^2 + 0.000000255D^3$
$dBA = 75.98 - 0.0747D + 0.0000035D^2 + 0.000000097D^3$
$dBA = 81.53 - 0.1307D + 0.0004216D^2 - 0.000000658D^3$
(D = distance behind belt in feet)
SOUND LEVEL (DBA)
100.00
92.50
85.00
77.50
70.00
62.50
55.00
47.50
40.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
DISTANCE (FT)

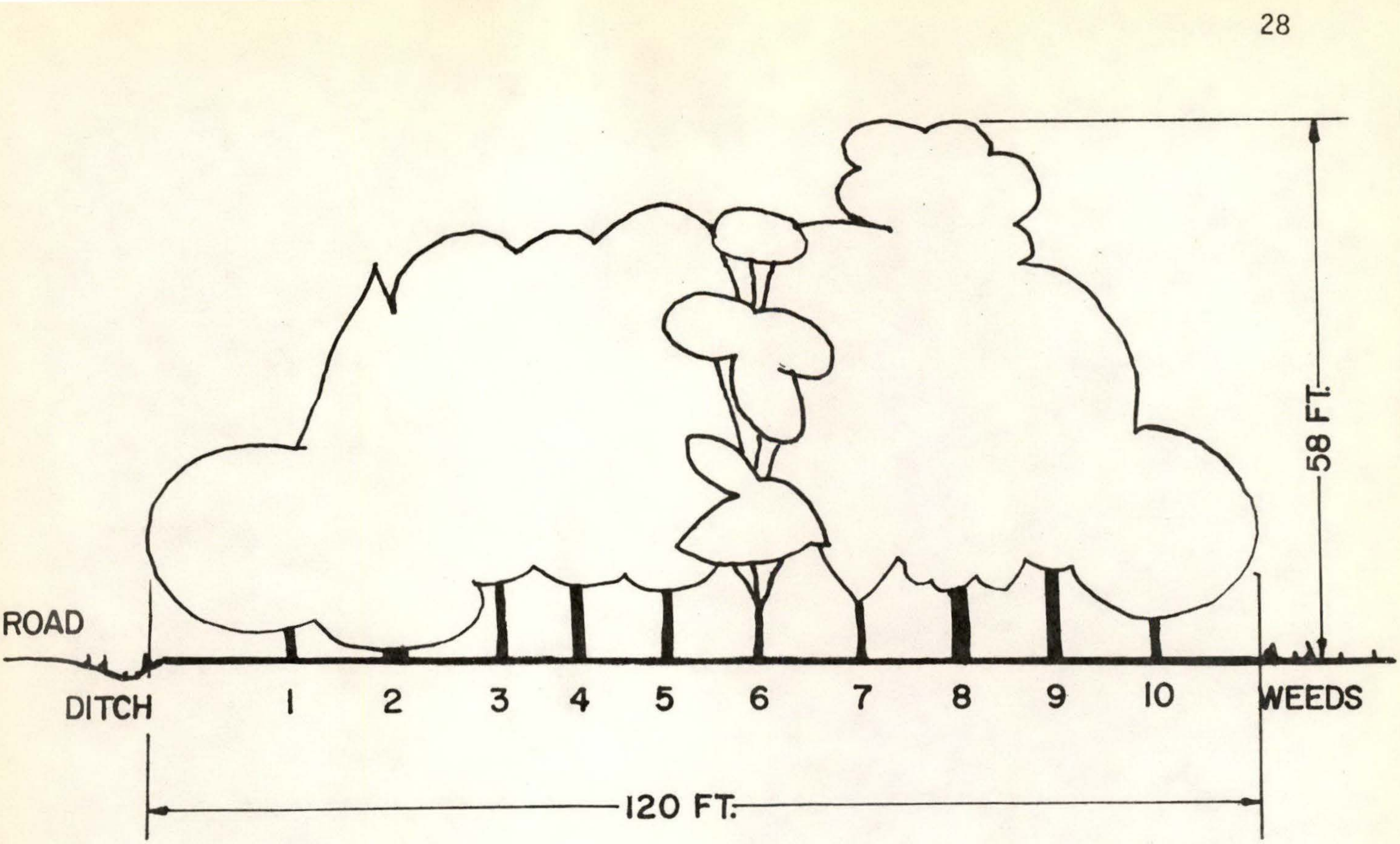

NOISE REDUCTION OF A TREE BELT
SOUND LEVEL AND ATTENUATION
VERSUS DISTANCE
SOUND LEVEL, dBA
90
80
70
60
50
AVERAGE SOUND LEVEL
(WITH TREES)
SITE 15Y
TEST 8-1,2
JUNE 3, 1969
△ DIESEL TRUCK
□ URBAN BUS
○ ARTERIAL AUTOS
ATTENUATION, dBA
10
5
0
EXCESS ATTENUATION
TREE BELT
0
50
100
150
200
250
300
350
400
450
DISTANCE FROM NOISE SOURCE, FEET


TEST NUMBER: 6
SITE LOCATION: 15Y
TREE TYPE: CD
TREE HEIGHT: 47
BELT WIDTH: 100
WIND VELOCITY: 7
HORN DISTANCE: 50
LEGEND
SOUND NUMBER..REPRESENTATION
1-1
1-2
2-1
2-2
3-1
3-2
SOUND LEVEL (DBA)
100.00
92.50
85.00
77.50
70.00
62.50
55.00
47.50
40.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
DISTANCE (FT)



NOISE REDUCTION OF A TREE BELT
SOUND LEVEL AND ATTENUATION
VERSUS DISTANCE
SOUND LEVEL, dBA
ATTENUATION, dBA
90
80
70
60
50
10
5
0
AVERAGE SOUND LEVEL
(WITH TREES)
EXCESS ATTENUATION
TREE BELT
SITE 15Y
TEST 6-1,2
MAY 23, 1969
△ DIESEL TRUCK
○ URBAN BUS
□ ARTERIAL AUTOS
0
50
100
150
200
250
300
350
400
450
DISTANCE FROM NOISE SOURCE, FEET


AVERAGE DIFFERENCE
(CONTROL-TEST)/N
LEGEND
SOUND NUMBER..REPRESENTATION
1
2
3
TREE LOCATION: 15Y
TREE HEIGHT: 47
BELT WIDTH: 100
NUMBER OF TESTS: 2
SOUND LEVEL (DBA)
0.00
2.50
5.00
7.50
10.00
12.50
15.00
17.50
20.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
MIKE DISTANCE (FT)

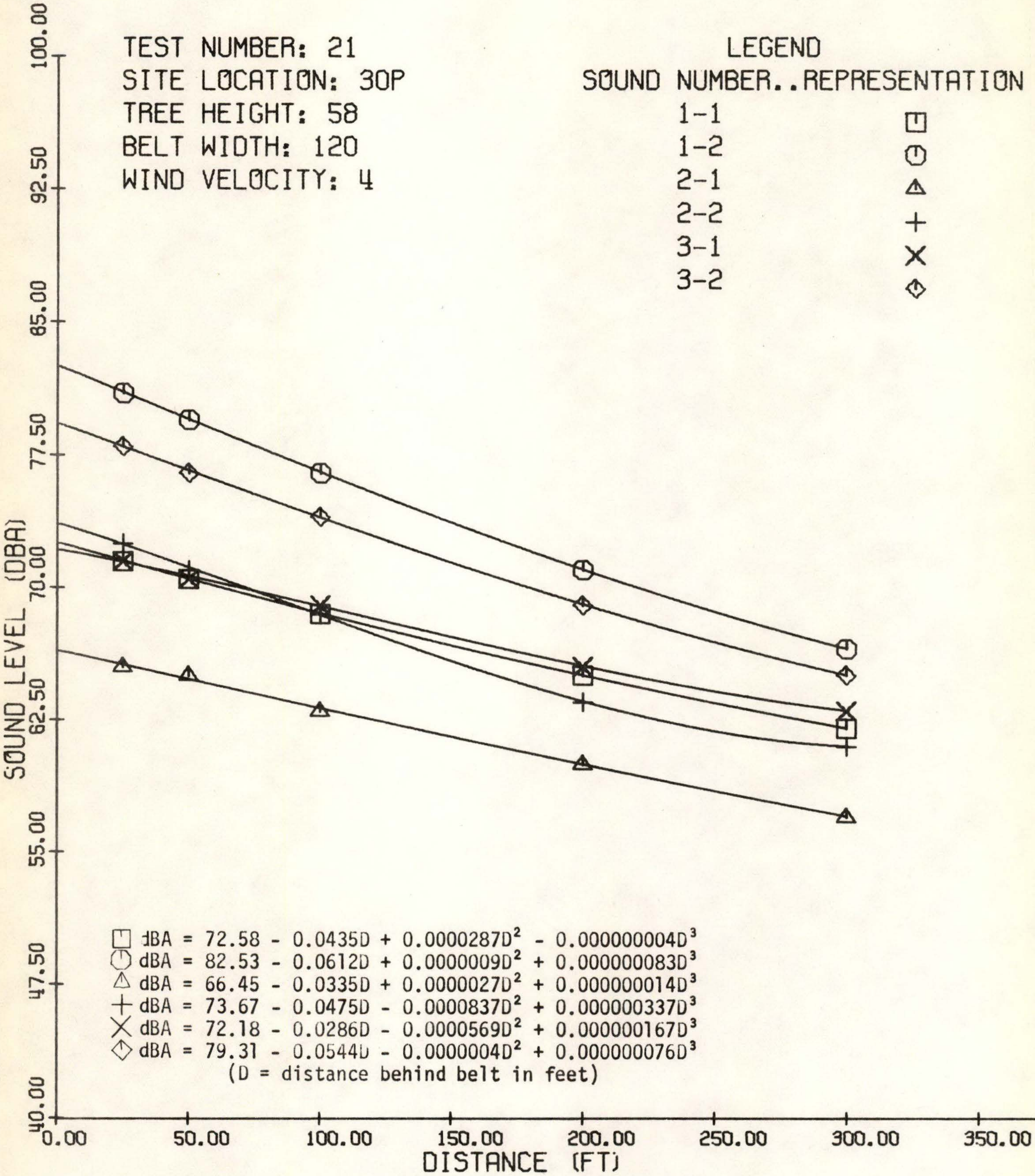


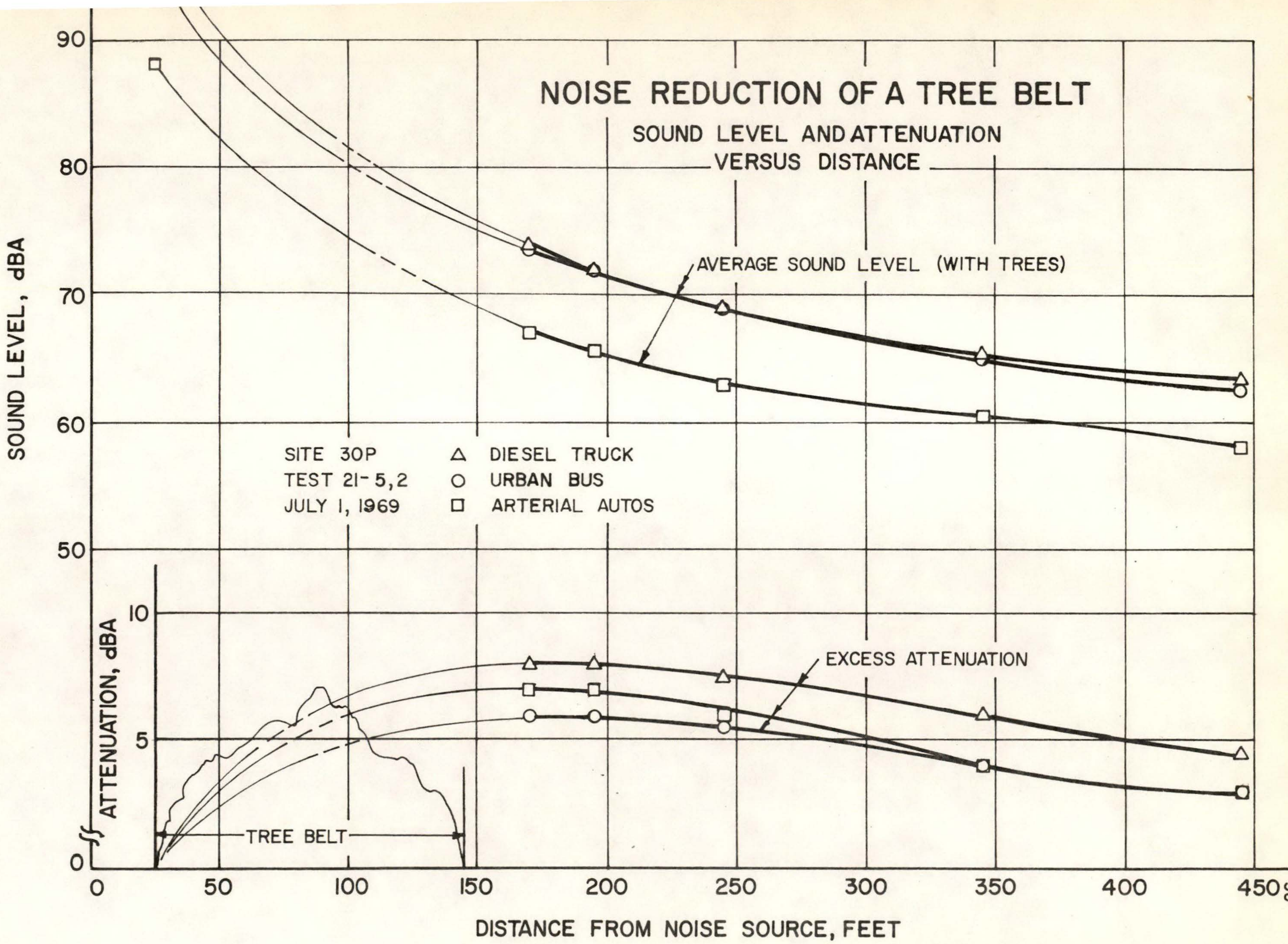
BELT NO. 30P ED DOBBERSTEIN FARM

10 ROW BELT S. TO N. 58 FT. TALL

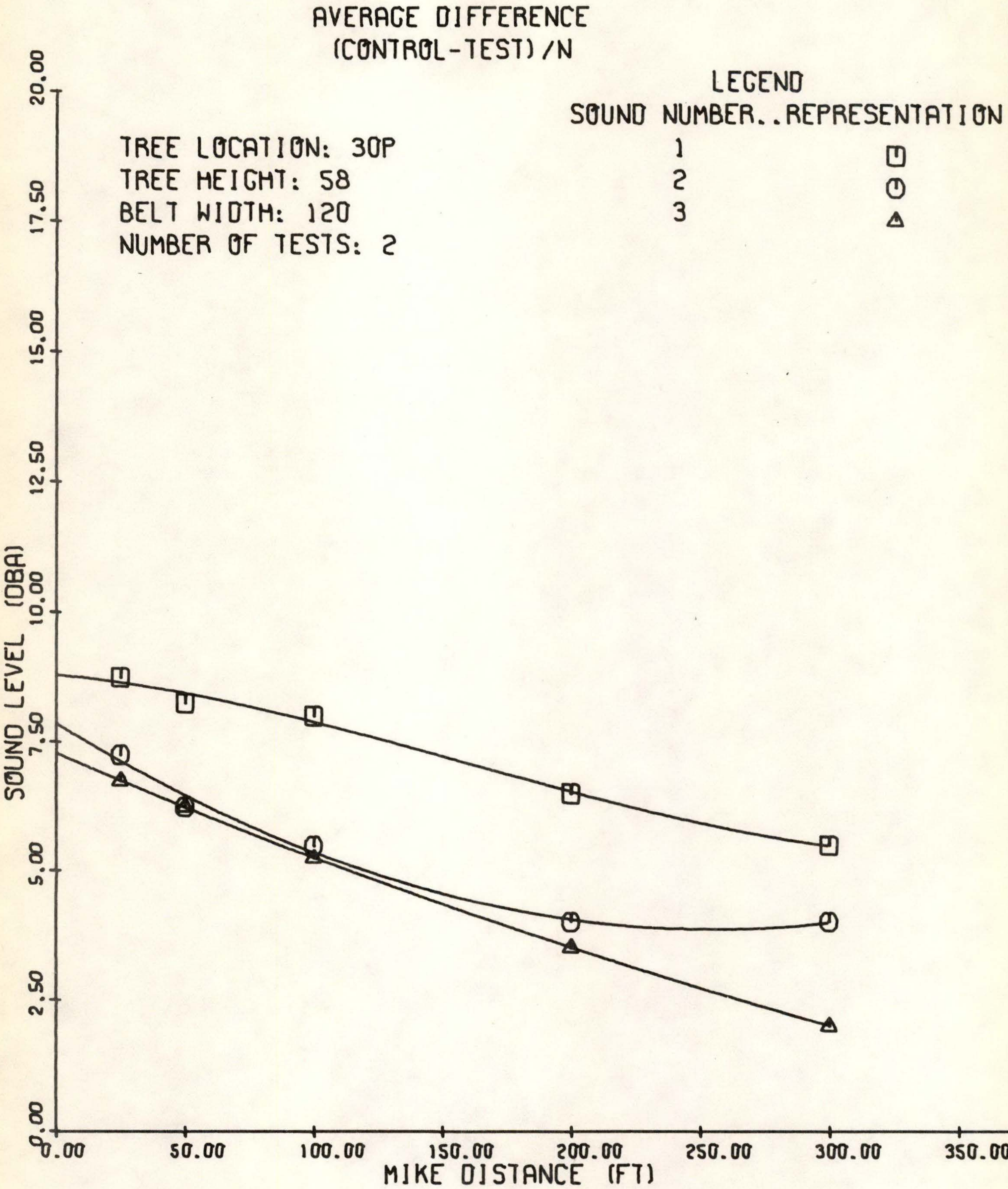
1. RUSSIAN OLIVE
2. PONDEROSA PINE - EASTERN RED CEDAR
3. GREEN ASH
4. GREEN ASH
5. HACKBERRY
6. HONEY LOCUST
7. SIBERIAN ELM
8. COTTONWOOD
9. HACKBERRY
10. MULBERRY

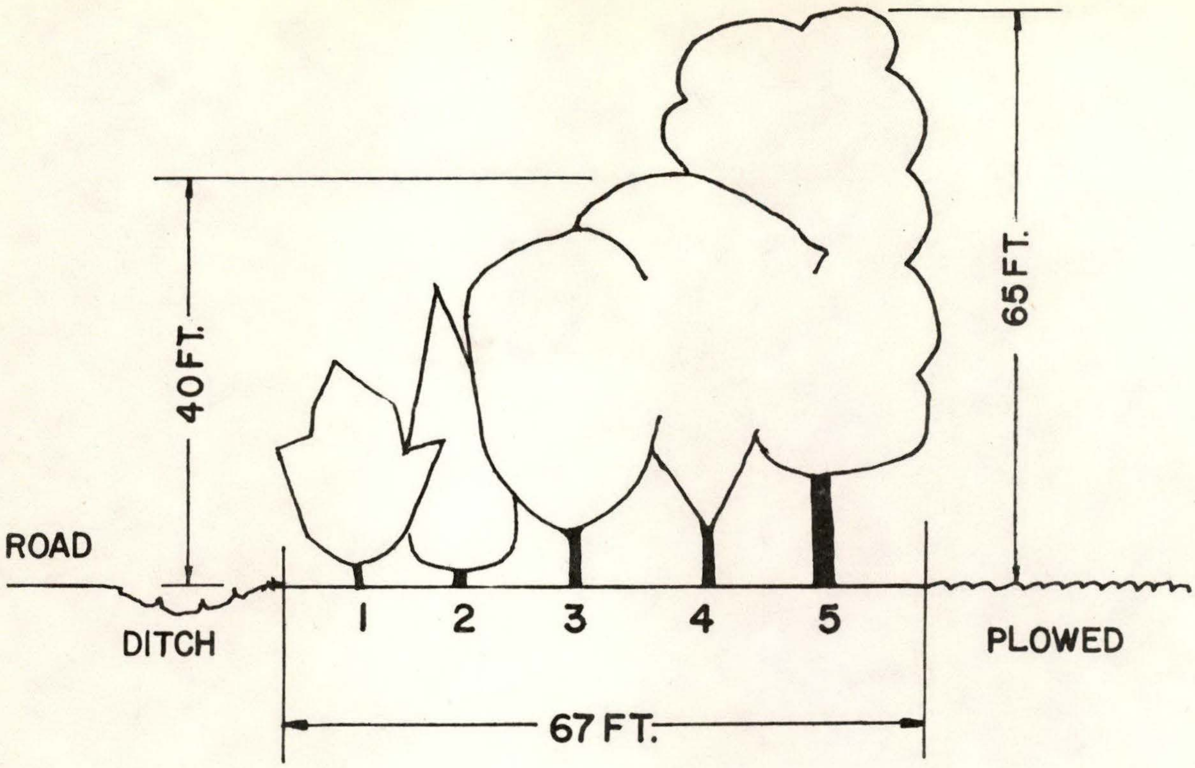
BETWEEN-ROW SPACING 10 FT.
IN-ROW SPACING 8 FT.
BELT WIDTH 120 FT.


TEST NUMBER: 21
SITE LOCATION: 30P
TREE HEIGHT: 58
BELT WIDTH: 120
WIND VELOCITY: 4
LEGEND
SOUND NUMBER..REPRESENTATION
1-1
1-2
2-1
2-2
3-1
3-2
dBA = 72.58 - 0.0435D + 0.0000287D² - 0.000000004D³
dBA = 82.53 - 0.0612D + 0.0000009D² + 0.000000083D³
dBA = 66.45 - 0.0335D + 0.0000027D² + 0.000000014D³
dBA = 73.67 - 0.0475D - 0.0000837D² + 0.000000337D³
dBA = 72.18 - 0.0286D - 0.0000569D² + 0.000000167D³
dBA = 79.31 - 0.0544D - 0.0000004D² + 0.000000076D³
(D = distance behind belt in feet)
SOUND LEVEL (DBA)
100.00
92.50
85.00
77.50
70.00
62.50
55.00
47.50
40.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
DISTANCE (FT)



NOISE REDUCTION OF A TREE BELT
SOUND LEVEL AND ATTENUATION VERSUS DISTANCE
AVERAGE SOUND LEVEL (WITH TREES)
SITE 30P
TEST 21-5,2
JULY 1, 1969
DIESEL TRUCK
URBAN BUS
ARTERIAL AUTOS
EXCESS ATTENUATION
TREE BELT
SOUND LEVEL, dBA
ATTENUATION, dBA
DISTANCE FROM NOISE SOURCE, FEET
0
50
100
150
200
250
300
350
400
450
90
80
70
60
50
10
5
0


AVERAGE DIFFERENCE
(CONTROL-TEST)/N
LEGEND
SOUND NUMBER..REPRESENTATION
1
2
3
TREE LOCATION: 30P
TREE HEIGHT: 58
BELT WIDTH: 120
NUMBER OF TESTS: 2
SOUND LEVEL (DBA)
0.00
2.50
5.00
7.50
10.00
12.50
15.00
17.50
20.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
MIKE DISTANCE (FT)

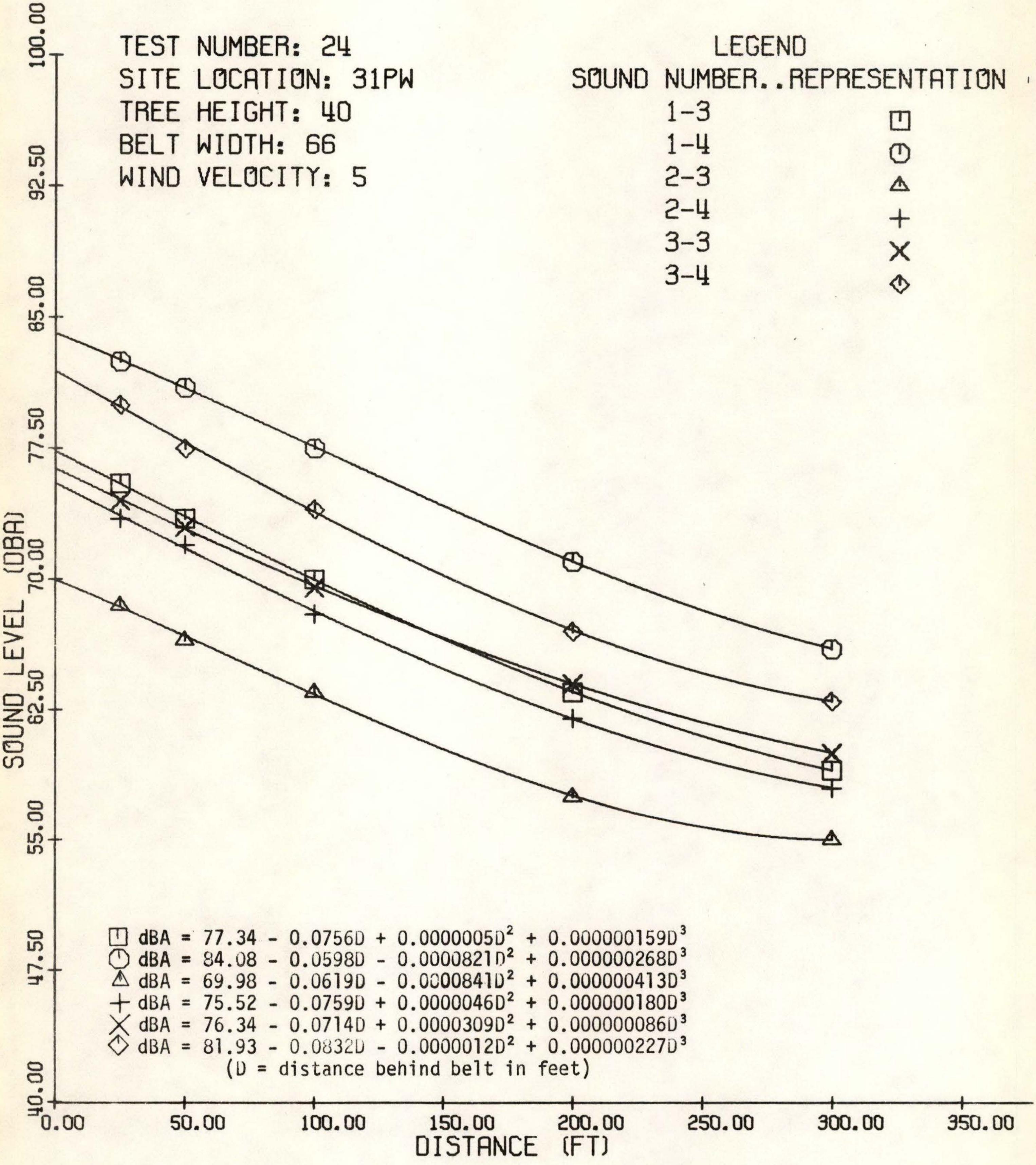


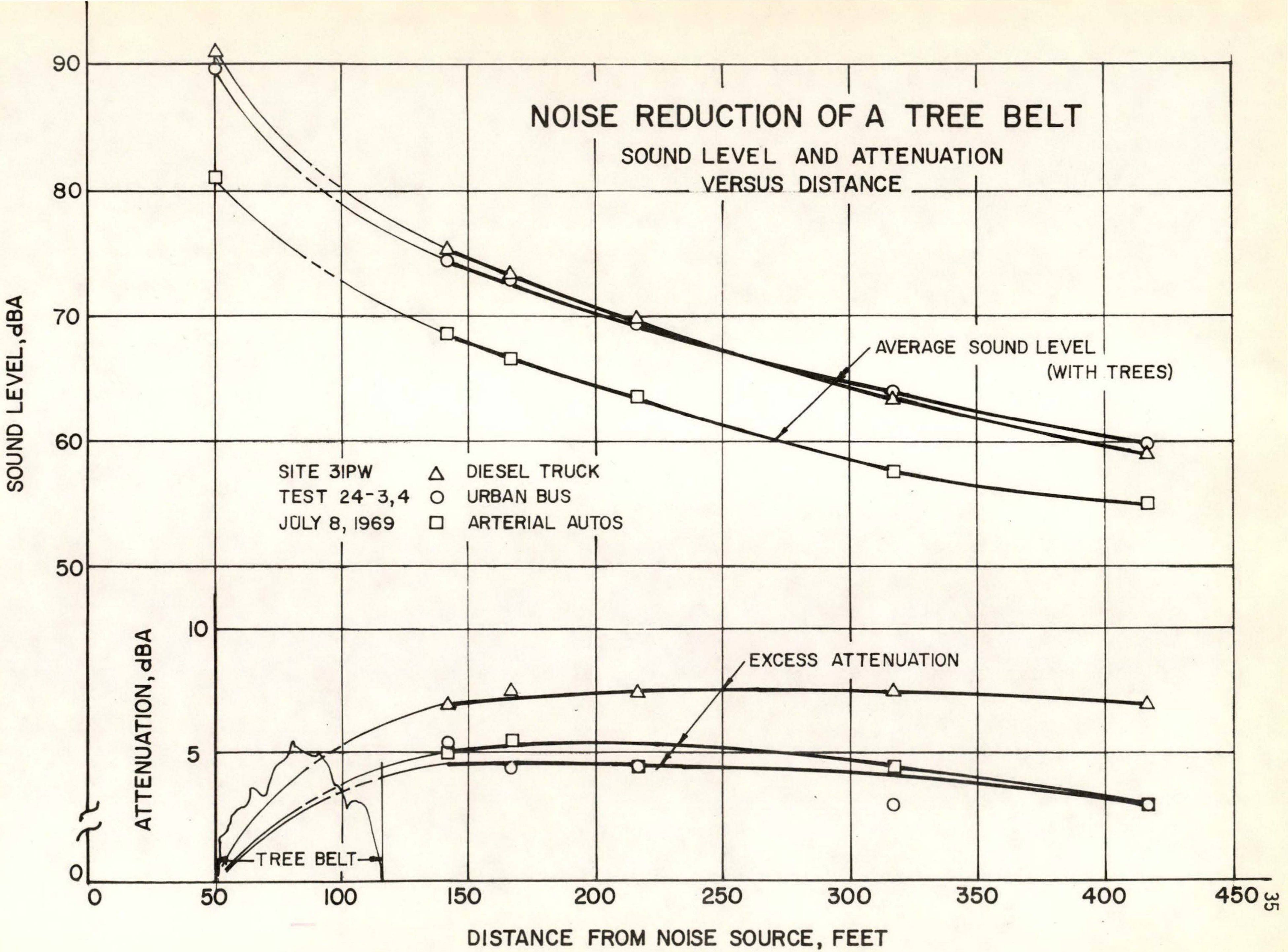
BELT NO. 31PW A. R. BURKE FARM

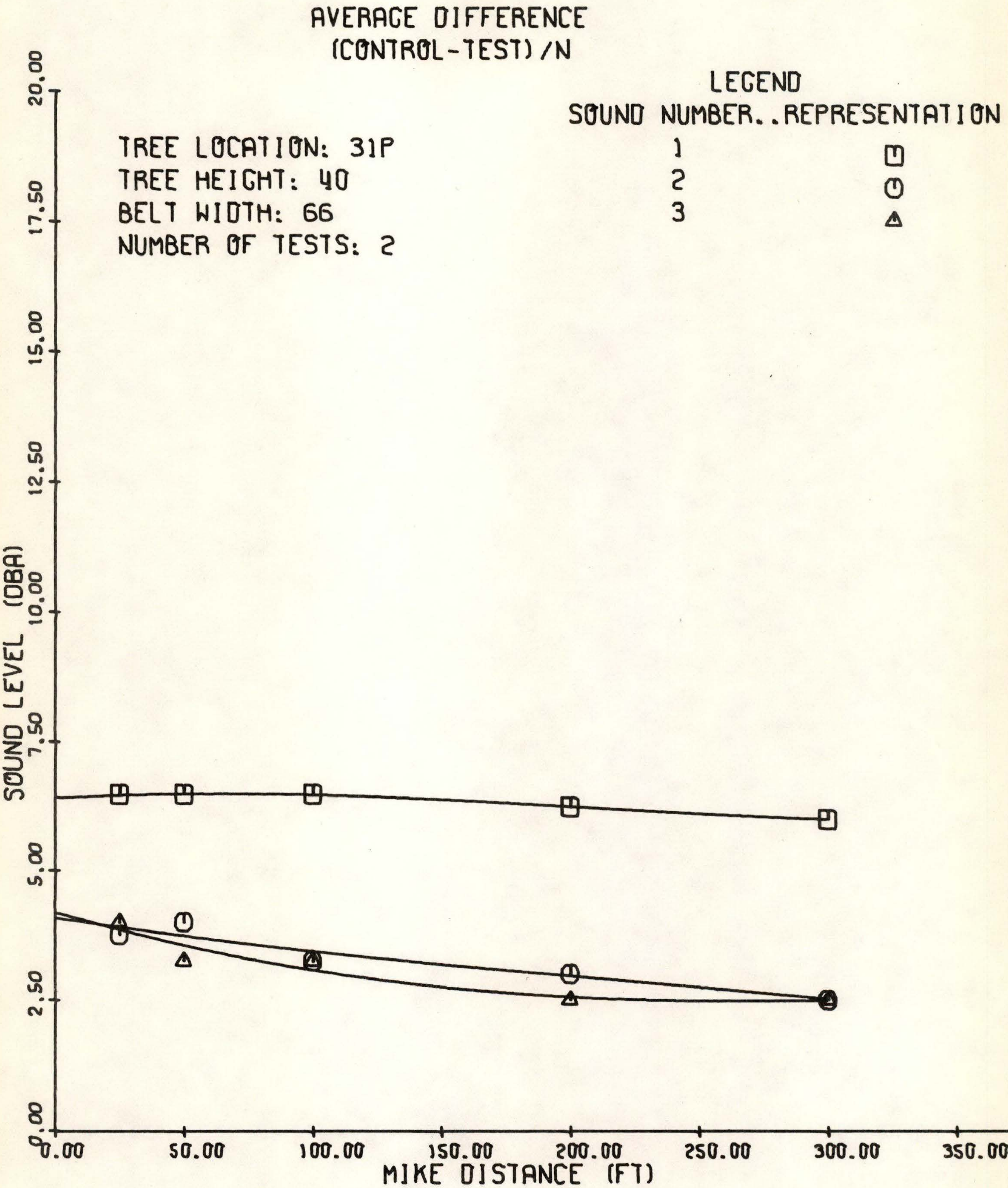
6 ROW BELT S. TO N. 40-65 FEET TALL

1. PLUM
2. EASTERN RED CEDAR
3. HACKBERRY
4. SIBERIAN ELM
5. COTTONWOOD
6.— RUSSIAN OLIVE (CUT)

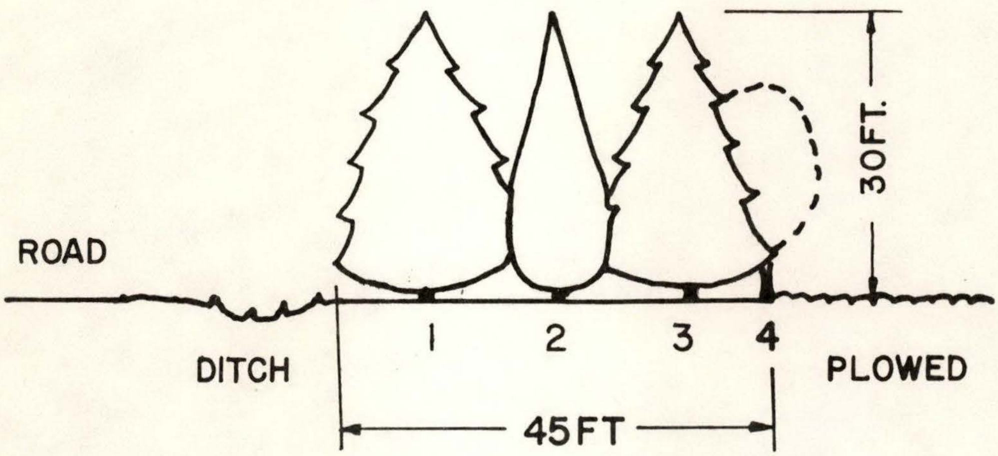
BETWEEN-ROW SPACING 12 FT.
IN-ROW SPACING 6 FT.
BELT WIDTH 67 FT.


TEST NUMBER: 24
SITE LOCATION: 31PW
TREE HEIGHT: 40
BELT WIDTH: 66
WIND VELOCITY: 5
LEGEND
SOUND NUMBER..REPRESENTATION
1-3
1-4
2-3
2-4
3-3
3-4
SOUND LEVEL (DBA)
100.00
92.50
85.00
77.50
70.00
62.50
55.00
47.50
40.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
DISTANCE (FT)
dBA = 77.34 - 0.0756D + 0.0000005D² + 0.000000159D³
dBA = 84.08 - 0.0598D - 0.0000821D² + 0.000000268D³
dBA = 69.98 - 0.0619D - 0.0000841D² + 0.000000413D³
dBA = 75.52 - 0.0759D + 0.0000046D² + 0.000000180D³
dBA = 76.34 - 0.0714D + 0.0000309D² + 0.000000086D³
dBA = 81.93 - 0.0832D - 0.0000012D² + 0.000000227D³
(D = distance behind belt in feet)


NOISE REDUCTION OF A TREE BELT
SOUND LEVEL AND ATTENUATION VERSUS DISTANCE
AVERAGE SOUND LEVEL (WITH TREES)
SITE 31PW
TEST 24-3,4
JULY 8, 1969
DIESEL TRUCK
URBAN BUS
ARTERIAL AUTOS
EXCESS ATTENUATION
TREE BELT
SOUND LEVEL, dBA
ATTENUATION, dBA
DISTANCE FROM NOISE SOURCE, FEET
90
80
70
60
50
10
5
0
0
50
100
150
200
250
300
350
400
450



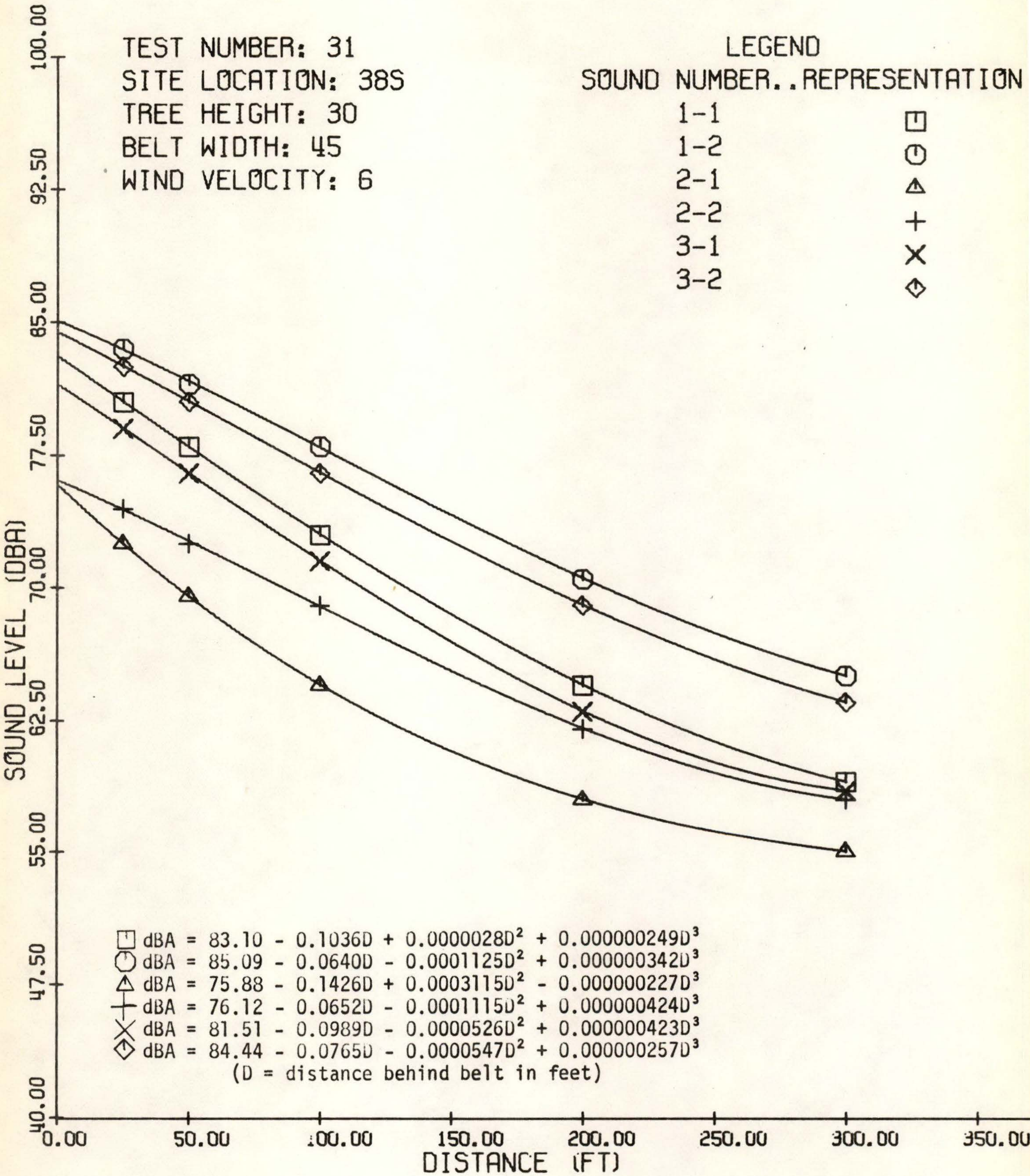
AVERAGE DIFFERENCE
(CONTROL-TEST)/N
LEGEND
SOUND NUMBER..REPRESENTATION
1
2
3
TREE LOCATION: 31P
TREE HEIGHT: 40
BELT WIDTH: 66
NUMBER OF TESTS: 2
SOUND LEVEL (DBA)
0.00
2.50
5.00
7.50
10.00
12.50
15.00
17.50
20.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
MIKE DISTANCE (FT)

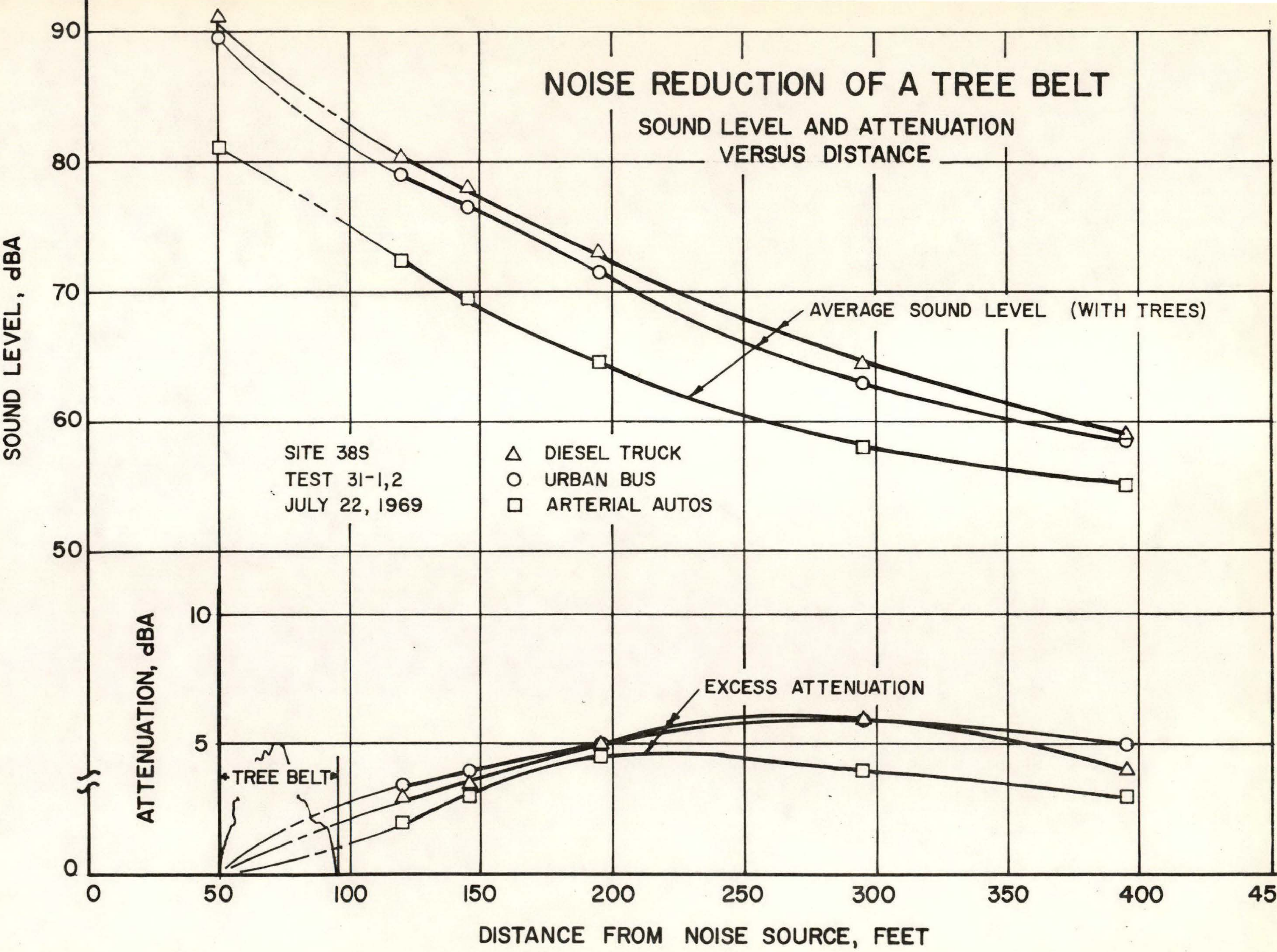


BELT NO. 38S MERLE SCHLUCKEBIER FARM

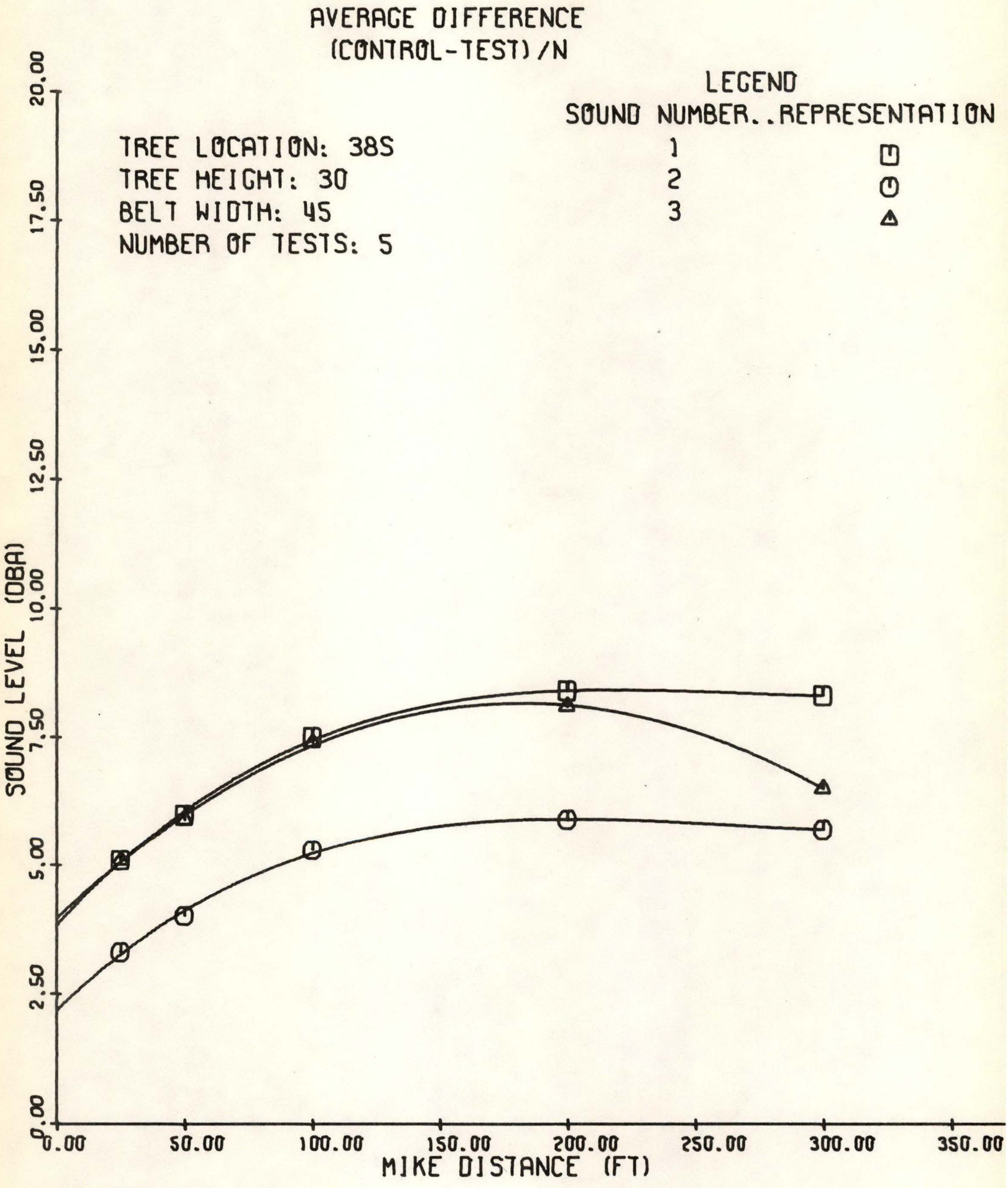
4 ROW BELT S. TO N. 30 FEET TALL
1. PONDEROSA PINE
2. EASTERN RED CEDAR
3. PONDEROSA PINE
4. APRICOT (VERY THIN - 1 OF 6 TO 10)

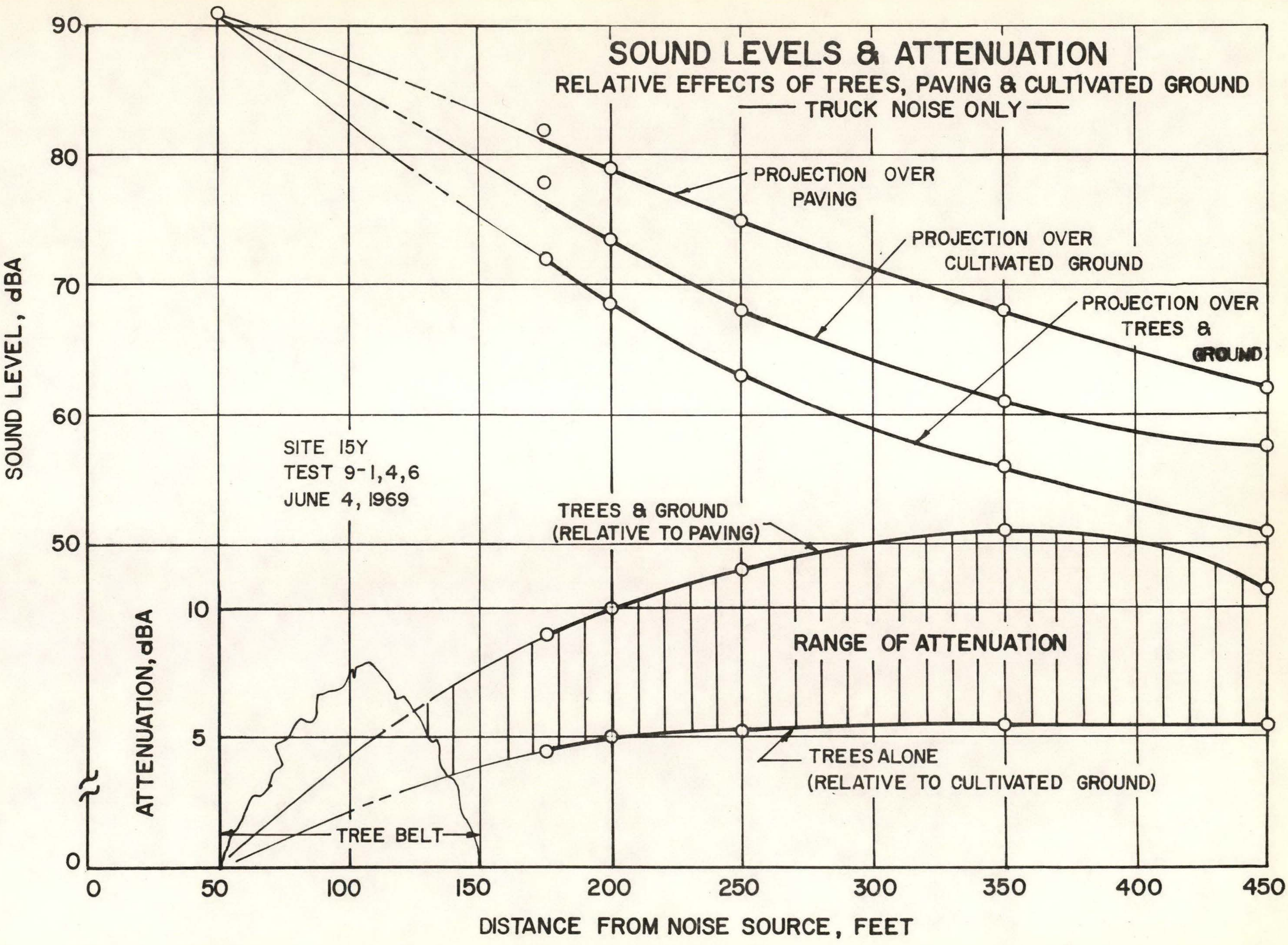
BETWEEN-ROW SPACING 12 FT.
IN-ROW SPACING 8 FT.
BELT WIDTH 45 FT.


TEST NUMBER: 31
SITE LOCATION: 38S
TREE HEIGHT: 30
BELT WIDTH: 45
WIND VELOCITY: 6
LEGEND
SOUND NUMBER..REPRESENTATION
1-1
1-2
2-1
2-2
3-1
3-2
dBA = 83.10 - 0.1036D + 0.0000028D² + 0.000000249D³
dBA = 85.09 - 0.0640D - 0.0001125D² + 0.000000342D³
dBA = 75.88 - 0.1426D + 0.0003115D² - 0.000000227D³
dBA = 76.12 - 0.0652D - 0.0001115D² + 0.000000424D³
dBA = 81.51 - 0.0989D - 0.0000526D² + 0.000000423D³
dBA = 84.44 - 0.0765D - 0.0000547D² + 0.000000257D³
(D = distance behind belt in feet)
SOUND LEVEL (DBA)
100.00
92.50
85.00
77.50
70.00
62.50
55.00
47.50
40.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
DISTANCE (FT)


NOISE REDUCTION OF A TREE BELT
SOUND LEVEL AND ATTENUATION
VERSUS DISTANCE
AVERAGE SOUND LEVEL (WITH TREES)
SITE 38S
TEST 31-1,2
JULY 22, 1969
DIESEL TRUCK
URBAN BUS
ARTERIAL AUTOS
EXCESS ATTENUATION
TREE BELT
SOUND LEVEL, dBA
ATTENUATION, dBA
DISTANCE FROM NOISE SOURCE, FEET
90
80
70
60
50
10
5
0
0
50
100
150
200
250
300
350
400
450

40


AVERAGE DIFFERENCE
(CONTROL-TEST)/N
LEGEND
SOUND NUMBER..REPRESENTATION
1
2
3
TREE LOCATION: 38S
TREE HEIGHT: 30
BELT WIDTH: 45
NUMBER OF TESTS: 5
SOUND LEVEL (DBA)
0.00
2.50
5.00
7.50
10.00
12.50
15.00
17.50
20.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
MIKE DISTANCE (FT)



SOUND LEVELS & ATTENUATION
RELATIVE EFFECTS OF TREES, PAVING & CULTIVATED GROUND
— TRUCK NOISE ONLY —
PROJECTION OVER PAVING
PROJECTION OVER CULTIVATED GROUND
PROJECTION OVER TREES & GROUND
SITE 15Y
TEST 9-1,4,6
JUNE 4, 1969
TREES & GROUND (RELATIVE TO PAVING)
RANGE OF ATTENUATION
TREES ALONE (RELATIVE TO CULTIVATED GROUND)
TREE BELT
SOUND LEVEL, dBA
ATTENUATION, dBA
90
80
70
60
50
10
5
0
0
50
100
150
200
250
300
350
400
450
DISTANCE FROM NOISE SOURCE, FEET

CHAPTER IV

OBSERVATIONS AND CONCLUSIONS

Factors Affecting Noise Reduction

Sound transmission (inverse of noise reduction) is affected by such known factors as distance, air turbulence, wind direction, temperature and wind gradients, humidity, and by media interposed between sound source and receiver. When only trees are present as the noise reducing medium between source and receiver, the structural components which may affect sound transmission are height of barrier, width of barrier, and overall density of barrier, as determined by species, planting patterns, tree spacing in the row and between the rows, and by foliage distribution.

The data show no apparent difference between trees of different species in their ability to reduce noise levels of the kinds of traffic noise studied. Thus we may infer that trees do not affect sound transmission by differences in leaf size and shape and branching characteristics (related to resonant absorption through wave length and frequency of the sound), but by height, belt width and overall density (related to diffusion through number and extent of the diffusing elements). Absorption is not ruled out completely, however, for noise type 1, which contains more high-frequency components than the other two noise types, does show a greater reduction, in most instances, than do the other types. In short it appears that other factors are more important than tree species in noise reduction. For example, tree size, primarily height, would appear to have an important effect on noise reduction. The "barrier" effect is greater with taller trees, and diffusion and absorption are spread over a larger area. The results do indicate, generally, that tree height is significantly correlated with noise reduction.

Noise reduction is naturally more complete in wider belts, due to the greater number of absorbing and diffusing elements present in a deeper belt. However, some rather large attenuations (sound reduction) were obtained in the narrower but fairly dense belts studied, although the wider belts, in general, gave the highest overall attenuation.

Belt density also undoubtedly affects noise reduction. The greater number of elements per unit volume in a dense belt than in a more open belt of the same dimensions, would provide a greater absorption area and more complete diffusion. A major problem arises, however, in attempting to relate noise reduction to belt density, because no completely satisfactory method has been devised for numerically measuring belt density. Belt density, as understood by the windbreak specialist, refers to the ability to reduce wind velocity. In most of the present experiments the wind velocity behind the trees was extremely low, indicating belts of near-maximum density.

Compensating factors, due to natural causes, appear to affect belt density and sound attenuation. The wider belts are relatively free of foliage and small branches within the belt, especially near ground level, and appear to be somewhat "hollow"; whereas, the narrower belts have foliage and small branches completely throughout the belt from top to bottom. These compensating factors probably account for the smaller-than-expected difference in the sound level attenuation of the wide and narrow belts. It would appear then, that while belt density is related to noise reduction in some unspecified way, no numerical relationship is feasible until a satisfactory method of measuring belt density can be devised.

Surface Considerations

The softness or hardness of the surface that the sound passes over markedly affects attenuation. This effect is primarily due to absorption of a soft surface as opposed to reflection from a hard surface. During the course of the experiments it was apparent that part of the attenuation observed was due to the trees, and part was due to the ground surface. Wherever possible, this difference was eliminated by making both the control test runs (without trees) and the regular test runs (with trees) over nearly identical surfaces. When inaccessibility, unfavorable terrain, or the presence of other factors which might have influenced the results, made surface duplication in the control runs impractical, correction factors were applied to the control run readings. Special tests, previously referred to, were made to develop surface correction factors for hard surfaces, as for a roadway; medium surfaces, as for short grass; or soft surfaces, as for tall grass, freshly plowed ground, or tall wheat stubble.

Finally, the results of the tests indicate that the type of surface over which a sound may pass is an important consideration in any research study or planning operation which includes sound transmission or noise reduction. The graph in Chapter III, entitled "Sound levels and attenuation", illustrates this point. The highest attenuation observed on the graph occurs in the case of trees and soft surface relative to hard-surfaced pavement. It is apparent that trees and grass, in an area which might otherwise be hard surfaced, would significantly reduce noise.

Atmospheric Considerations

Atmospheric gradients of temperature, humidity and wind velocity have recognized effects on sound transmission (and noise reduction). These

effects are variable and uncontrollable. They pose a major problem for the experimenter, and contribute to daily variations in sound level readings, which can neither be completely accounted for nor accurately adjusted to eliminate the variation. The effects can be minimized on a given day by making "tree" runs and "control" runs in immediate sequence, and by following the standard procedure of using similar surfaces, and sound projection in the same direction for both "tree" runs and "control" runs.

When test runs on a given belt extend over a period of several days, the results can be averaged to give a more accurate result than would be obtainable with a single test. Because of the complexity of the measurements, and the inability to control atmospheric variation, no attempt was made to relate atmospheric considerations to sound transmission. One exception was the consideration of wind velocity, which has been largely postponed in this preliminary report, but will be studied in more detail and included in the final report.

Although a detailed study of wind velocity effect has been deferred for the present, it may be stated that wind direction has a major effect in noise transmission (and reduction). Trees are most efficient as noise screens when they are placed down wind from a noise source. This is especially true when distances from source to receiver are in the 200 to 600 foot range, or greater. Seasonal variations of wind direction should, therefore, be considered in a planting design.

Placement of Tree Belts

The distance from sound source to the front edge of a belt of trees is often governed by right-of-way requirements, in the case of major

highways and by anticipated use of the space for other purposes, as for pedestrian traffic, etc. The presence of large trees closer than 50 feet from the edge of a roadway is believed, by some highway designers, to pose a threat to auto safety, due to possible collision. This 50-foot distance is also necessary to prevent snow from drifting over the highway, or branches from being blown onto the highway by high winds. Also, trees placed too close to highway intersections tend to decrease visibility. For this reason, and others, most of the tests in the present series were run at noise source distances of 50 feet from the front edge of the tree belt.

A limited number of tests were run at distances of 10, 25, 100 and 200 feet from the belt. The shorter distances are most pertinent within cities, where trees and shrubs could be used to screen sidewalks, shops, parks, etc. from traffic noise. These limited tests indicate that, for the heights of trees studied, any advantage in placing trees closer than 50 feet from the noise source would be limited to the use of dense conifers and shrubs in urban areas. It is significant that, when the distance from sound source to front edge of belt was large, i.e. 100 - 200 feet, the effectiveness of trees in reducing noise was diminished. It seems certain that if a choice is to be made between placing trees close to the receiver or close to the noise source, the more efficient use is to place them close to the source. For the shorter shrubs, a placement in the 10 to 25 foot range would seem desirable, where such use is permitted. A more extensive study of tree placement is anticipated for inclusion in the final report.

Acceptable Noise Levels

Acceptable noise levels differ greatly, depending on environmental surroundings, personal preferences, and practical necessity. Various criteria have been proposed, from time to time, for acceptable noise levels, and several methods have been devised for rating them. One such method is based on a so-called "Speech Interference Level", abbreviated (SIL) for technical usage. The speech interference level, measured in decibels, is the arithmetical average of the sound pressure levels of the noise in the three standard octave bands with center frequencies of 500, 1000, and 2,000 Hz (cycles per second).

Speech interference levels which are below 60 dB will permit normal conversation at a distance of 3 feet, whereas a moderate raising of the voice is required at a distance of 6 feet. Levels below 50 dB are generally considered desirable for residential districts.

A second method for rating noise levels is based on a series of numbered curves which emphasize the greater sensitivity of the ear to higher frequencies. The noise is first analyzed in octave band widths, then the decibel level of each band width is plotted on the curves, to give the octave band spectrum. A noise rating number "N" is picked from the curve which lies just above the octave band spectrum. This number is then corrected by reference to tables, in order to provide for adjustment to specific circumstances.

Other criterion for acceptable noise levels have been determined by personal-interview type surveys to meet special requirements. Because of ease of application and general acceptance the "Speech Interference Level" is believed to be the most desirable criterion for use in the present study and its application. Where tree barriers are to be used to reduce noise

levels, the experimental curves found on pages 13, 18, 23, 25, 30, 35 and 40 may be applied, and the expected dBA noise levels at various distances may be determined therefrom.

Should it be desired to convert from dBA units as found in the experimental curves, to speech interference level units, for certain applications, the following table may be applied for noises of the three types used in the experiments. Sound pressure level dB (flat response) is also included for reference.

TRAFFIC NOISE LEVEL CONVERSIONS, SIL, dBA, dB(FLAT)								
NOISE TYPE 1			NOISE TYPE 2			NOISE TYPE 3		
SIL	dBA	dB FLAT	SIL	dBA	dB FLAT	SIL	dBA	dB FLAT
43	50	53	45	50	56	45	50	53
53	60	63	54	60	65	55	60	65
62	70	72	66	70	76	65	70	73
73	80	83	75	80	86	75	80	83
83	90	94	84	90	96	84	90	92

Table 1

The use of the table and curves in designing a tree planting is illustrated by the following example: Let it be required to establish a recreational site adjacent to a major highway, on which large trucks are frequently traveling, and to select a tree planting which will result in a speech interference level of no more than 60 dB at the site. How close to the highway may the site be placed, and where in relation to the highway should the tree planting be placed?

Solution: Referring to Table 1, it is seen that a 62 dB speech interference level corresponds to a 70 dBA noise level, for noise type 1 (large truck). Interpolating between successive noise levels yields a 68 dBA level for the 60 dB SIL required. Referring to the Noise Reduction Curve on page 23 for site 15Y we see that a distance of about 250 feet from the highway, for a tree planting of the type represented by site 15Y, is necessary for the 68 dBA requirement. A distance for the tree planting of 50 ft from the highway is chosen as being the most efficient and within acceptable safety standards. The curve for site 15Y also corresponds to this 50 ft distance. Other tree plantings may be selected which will yield different distance requirements; and several trials may be necessary before the most appropriate planting is found. Unusual atmospheric conditions may cause noise levels to vary somewhat from those anticipated by the foregoing determination. For this reason a "margin of safety" of at least 50 feet should be applied to any location determined by the above procedure.

Value of Trees as Noise Screens

The value of trees in reducing noise levels can be approximated by reference to the various curves found at the beginning of this chapter. It may be observed that the upper limit of sound level attenuation is approximately 10 dBA. This amount of reduction corresponds roughly to "half as loud." Special surface conditions already described in "Surface Considerations," are an integral part of the valuation. When combinations of trees and grass are used the net reduction of sound level, when compared to hard pavement type surfaces, is considerably greater, reaching attenuations as high as 15 dB, or approximately one-third as loud.

It is apparent that the value of trees as noise screens is therefore somewhat relative to the type of surface over which the sound passes, and that the precise separation of the two effects is not an easy matter, mainly because belts of trees are not found in the center of large paved surface areas. Nevertheless, there are many reasons for concluding that attenuations from 10 to 15 dB can be attained by the use of trees alone, when the sound level is relative to projection over a hard surface.

Special Considerations for the Preliminary Report

The preliminary report was prepared approximately 10 months before the final report, with certain compromises made in the interest of time. Results of the experiments are in the form of dBA readings, a generally accepted unit for the measurement of broad band noises, such as traffic noises. Other units of reporting loudness, the Phon and the Sone have been deferred until the final report, where there use is anticipated to an extent not fully determined at this time. Accuracy of results in the final report is expected to be greater than in the preliminary report, due to improved techniques in experimental procedure. Only a brief study of the sound-reducing characteristics of trees relative to hard surfaces was made in the preliminary report, whereas an expansion of this area seems desirable for inclusion in the final report. A preliminary discussion of physical concepts relating to sound and its transmission was not included in the preliminary report, but this will be done for the final report. Other material not foreseen at this writing may be included in the final report as time permits.

CHAPTER V

RECOMMENDATIONS

Recommendations Based on the Present Study

Recommendations which follow should be considered in the light of the preliminary nature of this report. For this reason they are somewhat general with more specific recommendations to follow in the final report.

1. The use of trees and shrubs as noise screens is recommended in areas where distances of 75 feet or more, between a noise source and a protected area, are available for plantings.
2. Belts of several rows of trees, planted as close together as practical, to form a dense barrier are recommended.
3. Taller varieties of trees having relatively uniform vertical foliage distribution are recommended.
4. Where noise screening is desirable on a year round basis, evergreens or deciduous varieties which retain their leaves throughout most of the year are recommended.
5. The placement of noise screens close to a noise source, as opposed to close to a protected area is recommended.
6. Where the use of tall trees is restricted, shorter shrubs and grass will give limited protection, and their use is recommended in these cases.

Recommendations for the Future

1. Long term studies with specially designed plantings, where tree species and ground surface characteristics could be under the direct control of the experimenter, offer the best possibilities for utilizing trees and shrubs to their fullest extent as noise screens. Property must be available for a period of several

years for this purpose.

2. Studies of trees and shrubs as noise screens in combination with solid barriers, such as earth mounds, might enable a more efficient use of vegetation, where the distance from noise source to protected area is limited.

3. Studies of trees and shrubs as noise screens when compared to sound projection over various types of ground surfaces -- hard surfaces, such as pavement; medium surfaces, such as short grass; and soft surfaces, such as tall grass -- are recommended as a continuation of the study to obtain results useable over a wide variety of conditions.